Structure Analysis of A Nuclear Utility Model for Policymakers

by

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ABSTRACT

A sensitivity study of a nuclear utility model was performed to determine whether the formulated model factors could produce precise dynamic interactions with each other so that policy makers can use the model in a real-life situation. The nuclear utility model has been created to analyze the impacts of utility manager's decisions on the performance and relative safety of the nuclear power plant with the system dynamics(SD) method. The model has been developed by other model builders who were sponsored by the MIT international Program for Enhanced Nuclear Power Plant Safety, a project within the MIT Center for Energy Policy Research.

The sensitivity analysis was performed on the all 221 parameters of the model, which were simulated with several different plausible assumptions. The sensitivity test of the model provided the reliability on the assumptions of the model structure or policies and model factors estimated from information gathered from industry. Additionally, it was shown that sensitivity analysis can be a useful tool for attaining an understanding of relation between the structure and behavior of the model, and the real-world system.

As a result of the sensitivity study, it was found that the nuclear utility system dynamics model can be an effective tool for policy makers only if a few variables get more precise data from the industry.

Thesis Supervisor: Dr. Kent F. Hansen
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Chapter 1

1.1 Introduction

In the work reported here, we have tested the sensitivity of the Nuclear Utility Model. This Model is a system dynamics (SD) model which has been created to analyze the impacts of utility manager's decisions on the performance and relative safety of the plant.

The management structure of a nuclear power plant has all the characteristics of a large, complex system with many elements. This complex system has many interactions among the different elements, and it can be subject to many sources of unpredictable internal and external change. These interactions and responses to change are often nonlinear and time-dependent. Therefore, it is very difficult for utility managers to predict precise impacts of their managerial decisions. However, SD can provide a mathematical tool to analyze such dynamic systems and the consequences of policy changes in the systems. The Nuclear Utility Model makes it much easier to predict the plant's behavior in at least qualitative terms through computer simulation.

The Nuclear Utility Model has been developed by three other model builders since the project began in 1991. The MIT international Program for Enhanced Nuclear Power Plant Safety, a project within the MIT Center for Energy Policy Research, sponsored this research to study the factors that affect nuclear plant operation. The numerous factors of the model, such as time delays and personnel usage, were estimated as best as possible from information gathered from various individuals at the sponsoring utilities.

The question addressed here is whether the model factors formulated from the information gathered could produce precise dynamic interactions with each other so that policy makers can use the model in a real-life situation. Although the model has been simulated to test different assumptions of the model structure or policies, we are not aware of their reliability. To wipe out this lack of confidence, we should be able to explain the causes of undesirable behavior mode, identify policy variables that are capable of eliminating the undesirable behavior, and attain an understanding of the relation between structure and behavior, and real world. All these purposes have been achieved through sensitivity analysis.

In performing the sensitivity testing of the model, we simulated all parameters except the initial variable of all stock variables with the different plausible assumptions. We represented all the results of sensitivity analysis through a graph for the plant capacity on-line. We reviewed all the results of simulations to identify the important variables and understand the relation between behavior and parameter's change.

The work presented here discusses whether or not the Nuclear Utility Model has the plausibility of the causal mechanisms chosen to represent the real world, the plausibility of the numerical values of the model parameters, the compatibility of individual assumptions with established knowledge, and the internal consistency of the full structure.

In the remainder of this report, we will describe the Nuclear Utility Model developed in Chapter 2, discuss the results of sensitivity testing in Chapter 3, and then present our conclusions in Chapter 4. The stock-flow diagrams, equations, and simulation results are given in three appendixes.

Chapter 2

2.1 Nuclear Utility Model

This chapter presents the overall description of the Nuclear Utility Model. The description is divided into the five main sectors; the nuclear power plant sector, the social sector, the governmental sector, the information sector, and the financial resources sector. The functional description, including computer representations and main casual relationships, for each of these sectors and their sub-sectors will be presented. The main sectors and their sub-sectors are shown in Table 2.1.

Model development began in 1991 at first by identifying the social and political factors that affect utility decisions regarding nuclear power plants. During 1991 - 1992, Policy Influence Path (PIP) charts were developed to analyze the external stakeholders that affect utility decisions. During 1993 - 1994, these research results were organized into a system dynamics model by C.K. Eubanks who concentrated on the social system and its responses to the performance of a nuclear power plant. During 1994 - 1995, the information sector was created by L.D. Simon, and the financial resources sector was built by M.G. Turek, who also connected all the sectors together.

The work so far has been developed through the "iThink/stella" [1] software which utilizes visualized techniques for modeling. In this thesis, the Nuclear Utility Model has been reformulated via "Vensim" [2] software, which provides many effective tools for structure analysis, simulation results analysis and interfaces with other software.

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[1] The commercial software produced by High Performance System, Inc., 45 Lyme Road, Hanover, NH 03755.

[2] The commercial software produced by Ventana Systems, Inc., 149 Waverley Street, Belmont, MA 02178.

Table 2.1 The main sector and their sub-sectors of the Nuclear Utility Model

main sector	sub-sector
Nuclear Plant Sector	1. Equipment Flow 2. Capacity Calculation 3. Defect Flows 4. Defect Sources 5. Learning Curves 6. Flow of Scheduled Work Orders 7. Flow of Unscheduled Work Orders 8. Maintenance Staff, Hiring Allocation and Overtime 9. Mechanics Time Allocation 10. Planners 11. Mandatory and Discretionary Inspections 12. Materials Specifications and Inventory 13. Engineer Allocation 14. Manager Allocation 15. Safety
Social Sector	1. Local and National Public Concern 2. Media 3. Interest Groups
Government Sector	1. NRC 2. Congress 3. SALP
Information Sector	1. Industry Events 2. Industry Problem Reporting 3. INPO 4. Report Screening 5. Problem Screening 6. Evaluation 7. Corrective Action Process 8. Interactions with NRC 9. Information Labor 10. Information Learning Curve 11. Information SALP Effect
Financial Resources Sector	1. Internal Finance 2. PUC 3. Budgeting and Allocation 4. Stock 5. Bond Rating Institutions 6. Economic and Random Effects 7. Perceived Financial Safety 8. Debt

2.2 Nuclear Plant Sector

The nuclear plant sector was derived from the DuPont Maintenance Model[3]. It is composed of fifteen sub-sectors. Basic calculations in this sector are the plant capacity factor and relative safety level. In order to determine capacity factor, we must determine how much equipment is functional. Thus, we must know how defects are being created and eliminated in the functional equipment. Defects are created by plant operations and are eliminated by maintenance, which is performed by personnel. Personnel levels and assignments are determined by budget allocations and work procedures.

The main causal loop of the nuclear plant sector, which is a dynamic hypothesis for developing the model, is shown in Figure 2.1. The two negative feedback loops in the causal loop diagram balance the relationship between the capacity and equipment which is affected by maintenance work. The nuclear plant sector can be used to determine the value of preventative maintenance (PM) and to test methods for gradually implementing a successful preventative maintenance program (PMP) with limited resources.

2.2.1 Equipment Flow (view 1)

The equipment flow sub-sector controls the states of the total pieces of equipment; fully functional, broken down, or taken down for PM. The flows among these three states are controlled by the other sub-sectors within the nuclear plant sector, such as equipment repair rate, inspection rate, and breakdown rate. The model diagram of this sub-sector is shown in the view 1 in the Appendix A.

Pieces of equipment to broken down and pieces of equipment perceived fully functional determine the fraction of equipment that is broken down, *frac equip bdwn*. If *frac equip bdwn* increases, the capacity decreases due to the pieces of equipment broken

[3] The DuPont Maintenance Model was developed to determine the reasons for low capacity factors at chemical plant.

down. The uses of a variable, *Equip Brokendown* can be explained easily through tree diagram of it, which is shown in Figure 2.2.

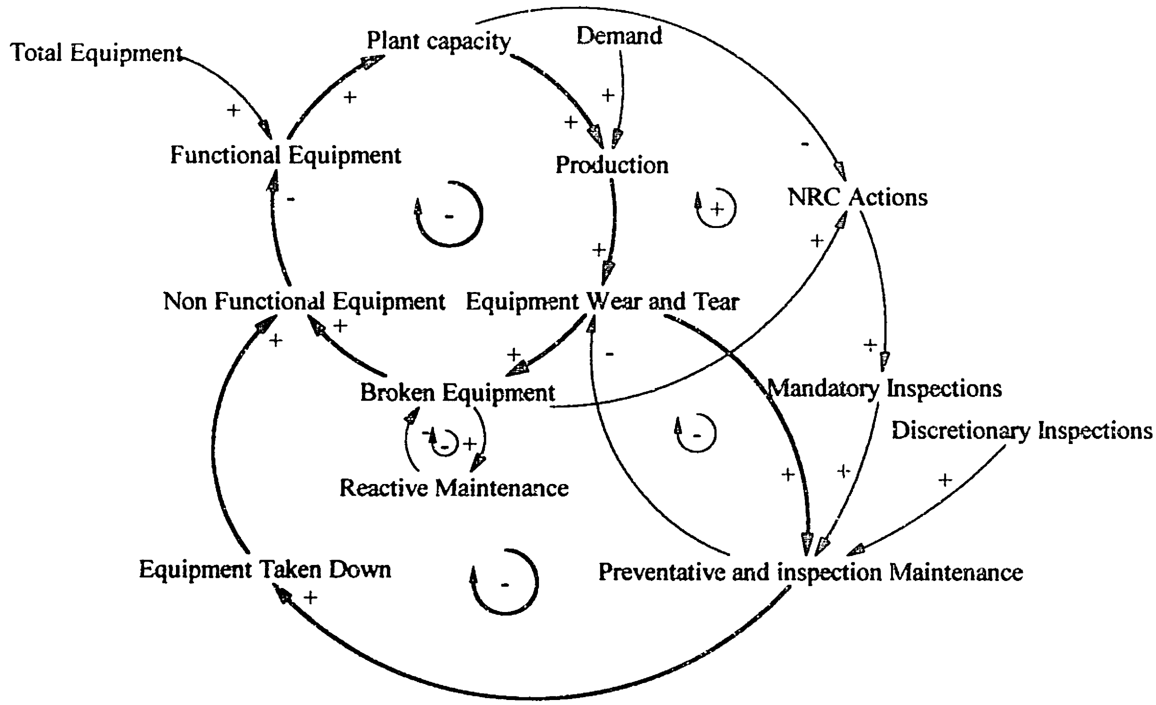

Figure 2.1 Causal Loop Diagram of Nuclear power plant sector

Figure 2.2 Tree Diagram of Equip Brokendown

Figure 2.3 and 2.4 shows respectively the uses of the variables, *Equip Perceived Fully Function* and *Equip Tagged for PM* through each tree diagram. The variable, *Equip Perceived Fully Function*, influences values of other variable such as manpower assignments with determining the number of pieces of equipment requiring inspections with the fraction of equipment requiring inspections. The variable, *Equip Tagged for PM*, is used in calculating values of the other variables such as the number of defects per equipment in PM system, *dfct per equip PM sys*.

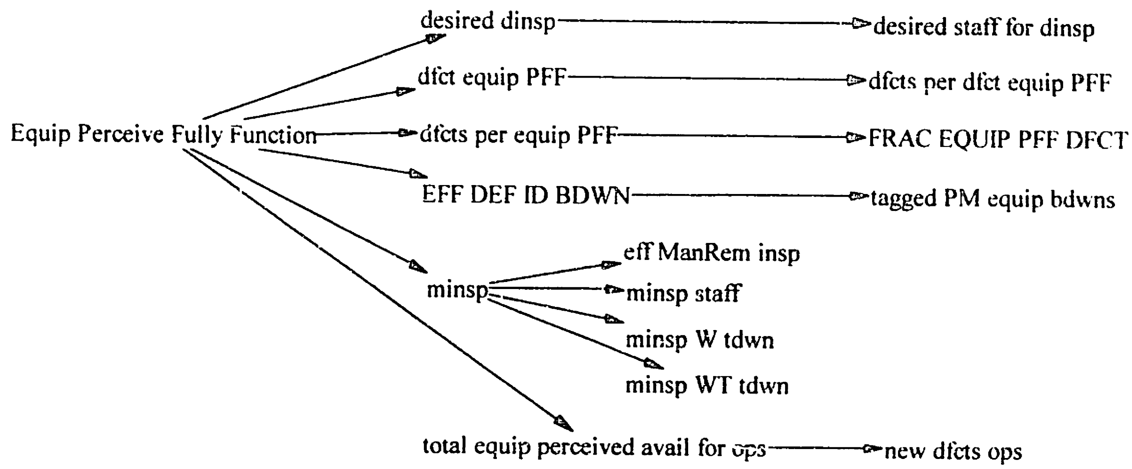

Figure 2.3 Tree Diagram of Equip Perceived Fully Function (PFF)

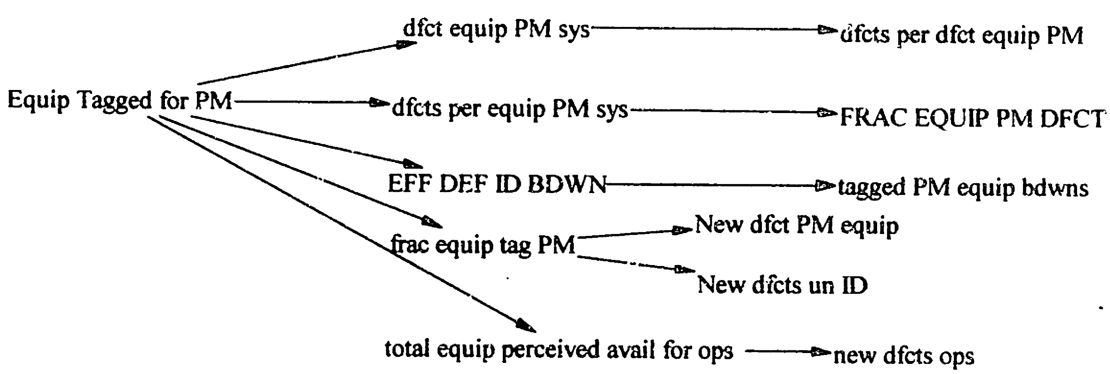

Figure 2.4 Tree Diagram of Equip Tagged for PM

2.2.2 Capacity Calculation (view 2)

The capacity on-line is a graphical function based on the percentage of equipment broken down or taken down by maintenance personnel. If equipment is taken down, it is expected that some prior planning has occurred so that it does not affect capacity on-line as severely. Forced outages affects the fraction of equipment that has been removed from service due to maintenance. As more forced outages occur, more pieces of equipment operating are taken down. The chance that broken equipment will cause a forced outage is described with a probability function. As more pieces of equipment break, the probability of one of those pieces causing a forced outage increases. Periodic outages also affect capacity in this sub-sector. Capacity on-line is calculated by the following equation. *capacity on line = MAX((1 - capacity bdwn - capacity tdwn) * 100, 0) * (1 - Periodic Outage)*

2.2.3 Defect Flows (view 3, 4)

The defect flows sub-sector describes the generation of defects, the mechanism of breakdowns due to defects, and the recovery process of defects through repair. The created defects stay in the equipment until they are identified or cause a breakdown. If not identified through inspections, defects will eventually cause a piece of equipment to breakdown. Likewise, even after mechanics identify a defect, it may causes a breakdown before repaired through scheduled maintenance.

2.2.4 Defect Sources (view 5)

In this sub-sector, defect generations are formulated. Defects are generated through normal operation of the plant, working on repairs or inspections, installing defective parts, or breakdowns of other equipment. As the plant ages, the rate of operation defects due to the wearing out of some equipment is increased.

2.2.5 Learning Curves (view 6)

2.2.5.1 Description

Learning curves are included in order to reflect some reduction mechanisms in defect generation over the plant life. There are many different types of learning within the plant but 6 important learning factors are considered in this model. As plant operation hours accumulate, operators learn how to reduce stress on components, and also wear and tear on components declines due to break-in of equipment. As mechanics accumulate repair hours, they make fewer mistakes. As personnel inspect more equipment, their inspection skills improve, so more defects are found at an earlier time. The impact of information and training on the nuclear plant sector is exerted mainly through this sub-sector. As training hours increase, the learning curves improve, and as the utility invests more in information use, defects decrease.

2.2.5.2 Computer Presentation

This sector was unified and simplified by using the subscript function of Vensim in order to give an optimized visual view and model structure. Subscripts allow a single variable name to represent more than one variable. Six different subscript constants such as WO, BE, DR, OE, IN and FO are introduced to represent the six learning mechanisms mentioned earlier. WO, BE, DR, OE, IN and FO respectively represent the learning mechanisms from the cumulative value of work orders completed, break-in of equipment, parts used, operator errors, events with corrective actions through information process, and forced outages. OE represents the learning mechanism from the cumulative value of The variable names using subscripts in this sub-sector are shown in Table 2.2. *XLearning and Training: WO, BE, DR, OE, IN, FO.*

Table 2.2 Variable Names of Learning Curves Sector

Variable Name	*Variable Type*	*Units*
CUM Correct Action	stock	corrective actions
INT CUM Correct Action	initial value	corrective actions
Event Occurance Rate	stock	event/week
INT Event Occurance Rate	initial value	event/week
Completed PM rate	flow	corrective actions/week
Rate decreasing	flow	event/week/week
learning curve	converter	fraction
MOD learning curve	converter	fraction
frac analysis	converter	fraction

Each of these variable names represents the six different variables. For example, the equation, *MOD learning curve[WO] = -LN(1- learning curve[WO]) / LN(2),* shows how to calculate one of the six 'MOD learning curve' variables represented by the variable name. The Vensim representation of this sub-sector appears in Figure 2.5.

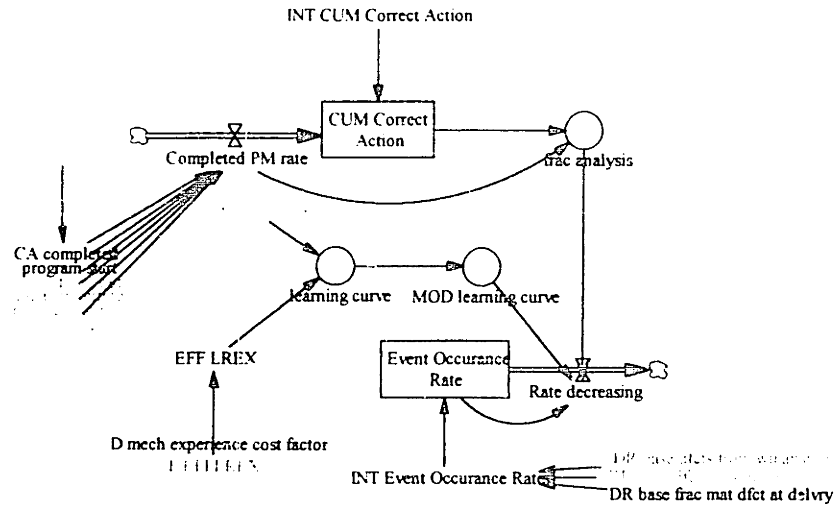

Figure 2.5 Vensim Diagram of Learning Curves Sector

2.2.6 Flow of Scheduled Work Orders (view 7 - 11)

2.2.6.1 Description

This sub-sector controls PM repairs. The flow of scheduled work orders includes work order creation, engineer review, manager review, material acquisition, equipment take down, and work in progress. Once the taken down equipment flows out of 'work in progress' (*Schd Work Order[S5]*), it is considered fully functional.

Discretionary inspections determine necessary repairs. The repairs are then scheduled, reviewed, and performed. Meanwhile, plans are created and materials are acquired for the job. The whole process is more efficient since the work is scheduled in advance. Additionally, workers introduce fewer new defects into the equipment, but the taken down equipment results in reduction of the plant capacity. Because of these two competing aspects of scheduled maintenance program, a balance has to be maintained in allocating mechanics and engineers between unscheduled and scheduled maintenance programs. If managers allocate too many people to the PM program, the broken equipment will not have a chance to be repaired.

2.2.6.2 Computer Presentation

The stock variables of work order are represented by using a subscript variable, *Xsched Work Order: S1, S2, S3, S4, S5. Schd Work Order[S1]* is a stock which includes work orders created and waiting for engineer review. *Schd Work Order[S2]* is the amount of work orders waiting for manager review. *Schd Work Order[S3]* is the number of work orders waiting equipment to become available before work may proceed. *Schd Work Order[S4]* is the amount of work orders waiting for material acquisition and equipment take down and *Schd Work Order[S5]* is the number of scheduled work orders in progress. Variables regarding this subscript variable are shown in Table 2.3 and a stock - flow diagram for the flows of work order is depicted in Figure 2.6.

Table 2.3 Variable Names of Flow of Scheduled Work Orders Sector

Variable Name	*Variable Type*	*Units*
Schd Work Order	stock	work order
INT Schd Work Order	initial value	work order
New schd WO	flow	work order/week
Forget schd WO	flow	work order/week
Completed schd WO	flow	work order/week
schd WO comp	converter	work order/week

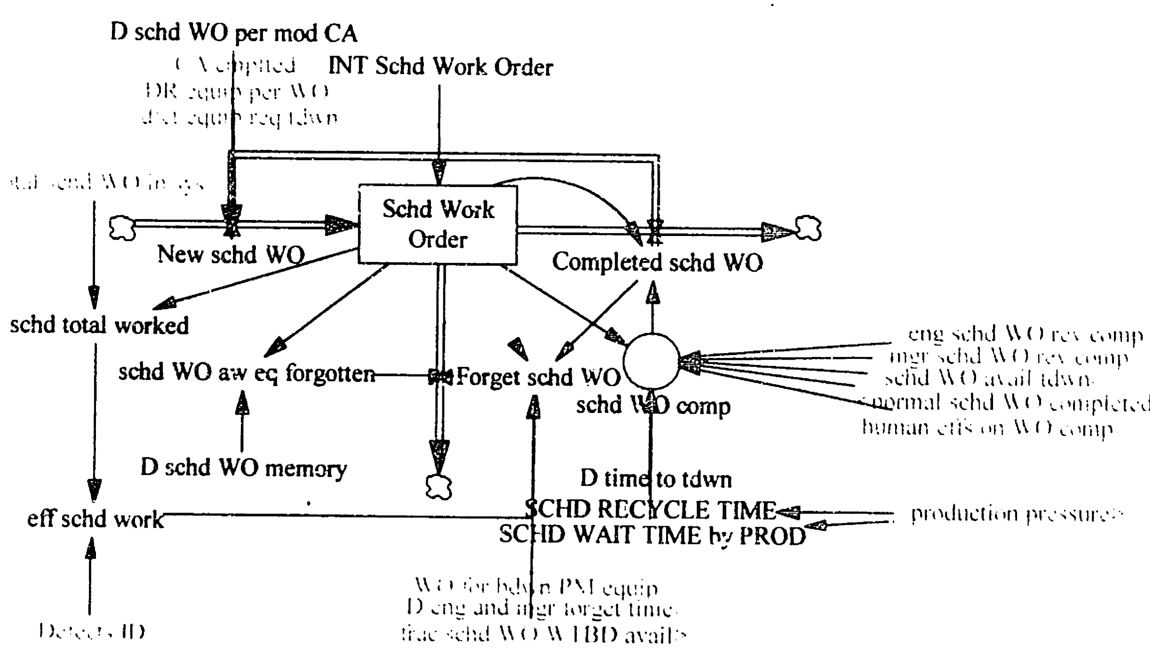

Figure 2.6 Vensim Diagram of Flow of Scheduled Work Orders Sector

2.2.7 Flow of Unscheduled Work Orders (view 13 - 15)

2.2.7.1 Description

This sub-sector accounts for the repair processes of all broken equipment. Once equipment breaks down, its repair process is simplified since it does not need to be inspected or scheduled first. However, since worker productivity is lower when fixing broken equipment, equipment stays down longer. Also, since equipment can not be taken down at desirable times, such as during a periodic outages, and ordering parts consumes more time, each down piece of equipment has a greater impact on plant capacity (M.G.Turek, 1995, p32).

The flows of unscheduled work orders has the same flows of scheduled work order such as work order creation, engineer and manager review, material acquisition, broken equipment take down, and work in progress. Once, the broken equipment flows out of 'work in progress', *Unschd Work Order[U4]*, it is considered fully functional. However, new defects could have been introduced during the repair process.

2.2.7.2 Computer Presentation

The number of unscheduled work orders using subscript variable, *Xunschd Work Order: U1, U2, U3, U4*, are also created. A stock, *Unschd Work Order[U1]*, is the number of unscheduled work orders created, and *Unschd Work Order[U2]* is concerned about engineer review. *Unschd Work Order[U3]* includes the material acquisition and broken equipment take down, and *Unschd Work Order[U4]* is the number of unscheduled work orders in progress. The variables using this subscript variable in this sub-sector are shown in Table 2.4 and a stock - flow diagram for the flows of unscheduled work orders is depicted in Figure 2.7.

Table 2.4 Variable Names of Flow of Scheduled Work Orders Sector

Variable Name	*Variable Type*	*Units*
Unschd Work Order	stock	work order
INT Unschd Work Order	initial value	work order
New unschd WO	flow	work order/week
Completed unschd WO	flow	work order/week
Forget unschd WO	flow	work order/week

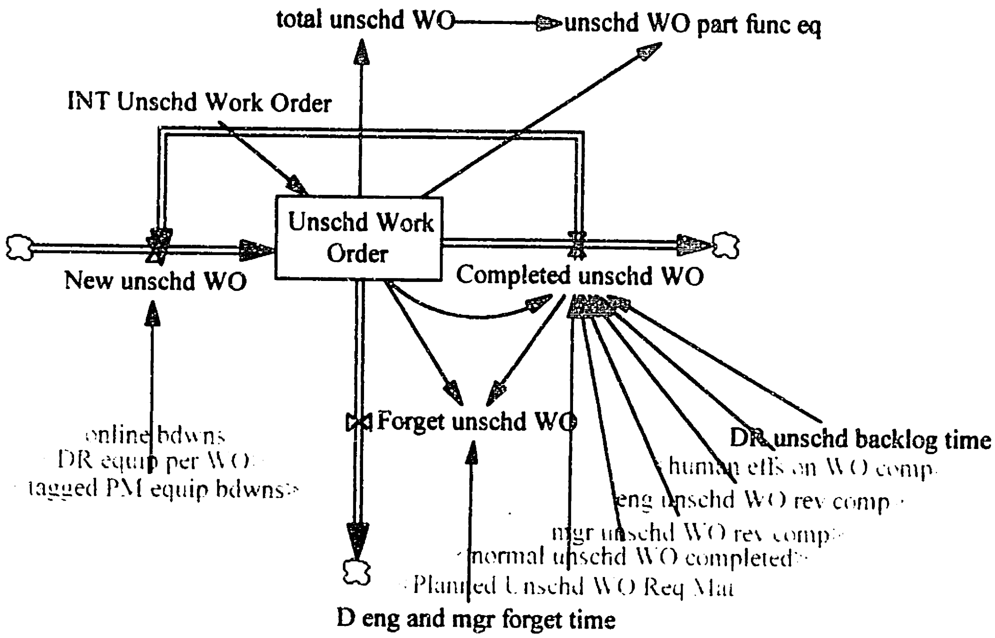

Figure 2.7 Vensim Diagram of Flow of Unscheduled Work Orders Sector

2.2.8 Maintenance Staff, Hiring Allocation and Overtime (view 16, 17)

This sub-sector is the core of personnel allocation. The allocation scheme of managers and engineers is similar. Only the functions of the personnel are different. Based on the budgeted allocation of resources, maintenance workers will be allocated into various tasks; maintenance, performing inspections, being trained or planning work orders. So, maintenance staffs are composed of mechanics for discretionary and mandatory inspections, maintenance workers, and planners. Other overhead type jobs are assumed to be a part of the all above tasks.

In this model, the maximum rate of hiring of maintenance staff is limited by fixed maintenance budget limit. Training has a short term adverse effect of reducing work time, but can provide a long term learning benefit. It is assumed that workers have to do overtime in case of a manpower shortage. As overtime increases, hiring increases. However, overtime has feedback on worker productivity with time delays. As overtime increases, worker productivity drops substantially. Alternately, if workers are under-utilized, their productivity will drop to fill the available time.

2.2.9 Mechanics Time Allocation (view 18)

This sub-sector determines the total number of weeks of maintenance work to be done (*week work TBD*), which determines the workload. The division of mechanics' time between scheduled and unscheduled maintenance is assumed as a fixed fraction. The mechanics react to the incoming workload each week by assigning the required number of mechanics to the work. If there are too few mechanics, broken equipment receives priority. Eventually, they will attempt to do all the required work by increasing overtime.

The number of backlogged work orders controls the capacity of the plant. This backlog represents the pieces of equipment that were not fixed at the end of the week. The pieces that are still broken reduce capacity.

2.2.10 Planners (view 19)

This sub-sector controls the creation and review process of maintenance plans. There can be a delay in performing a work order because of time spent waiting for a correct plan for the job. If a plan for a job already exists in the plan library, the job is expedited. Otherwise, the worker must wait for a plan to be written and reviewed. The number of the plans which are completed is determined by the planners available to create a plan and their productivity.

2.2.11 Mandatory and Discretionary Inspections (view 20, 21)

The budget allocator has the greatest direct impact on plant performance in this sub-sector. The 'budget allocator' mentioned throughout this discussion is the person who chooses budget parameters before the running the model. The budget allocator can control the number of discretionary inspections by assigning more mechanics. The Nuclear Regulatory Commission (NRC) can also affect more on the scheduled maintenance through mandatory inspections. As mandatory or discretionary inspections increase, the number of defects found increases, which will increase the number of scheduled work orders. The total number of defects which are identified from mandatory and discretionary inspections, *dfct ID from insp*, is determined in this sub-sector.

2.2.12 Materials Specifications and Inventory (view 22, 23)

A mechanic needs repair parts to do his task. One can invest money in new capital equipment or improve specifications of existing equipment and repair parts in this sub-sector. Improving parts quality specifications reduces the number of defects per part. Buying all new equipment reduces the average age of equipment in the plant, reducing operations defects in that equipment. In this model, a proper *Stores Inventory* should be maintained by allocating some money. If *Stores Inventory* do not have quantities enough to supply the amount of *parts needed*, it is assumed that as many parts as in the inventory are consumed. Also, The total number of parts in the *Stores Inventory* is increased by accepting parts first, and then decreased by the number of parts consumed.

2.2.13 Engineer Allocation (view 24 - 26)

The model allocates engineers as it does mechanics. They are categorized into two different groups, *Rookie Engineers* and *Pro Engineers*. The maximum number of engineers allowed to be hired is limited due to allocated budget, *max bud eng*. Engineers are allocated to maintenance, planning and information tasks. They also work overtime with lower productivity. One can allocate engineers among the different tasks such as maintenance, planning, and information.

2.2.14 Manager Allocation (view 27 - 29)

Managers are also allocated in a similar manner. They are just more expensive and there are fewer. Their tasks are finance, maintenance, and information.

2.2.15 Safety (view 30, 31)

The safety sub-sector includes calculations of Man-Rem, Forced Outage Frequency and Estimated Core Melt Frequency, which are the measures of the safety. The Man-Rem estimate is determined by multiplying the amount of maintenance done by an average Rem per work order. The Forced Outage Frequency is a probabilistic calculation based on the current average forced outage frequency for nuclear power plants multiplied by a ratio of broken equipment and operator astuteness. Operator astuteness is determined primarily by training and information. The Estimated Core Melt Frequency is determined by multiplying the current base core melt frequency (1/20,000 reactor-years) by operator astuteness, broken equipment, total defects, and forced outage frequency factors. This calculation is not rigorous, but it provides a consistent simplified effect on overall core safety (M.G.Turek, 1995, p34-35).

2.3 Social Sector

The social sector concerns impacts on plant operations due to public concern. The impacts are through NRC actions. Factors that cause NRC actions are relative to activities of interest groups. Interest groups stimulate the media and Congress to put pressure on the NRC.

The social sector includes the local public, national public, media and interest groups sub-sectors. Each of these sub-sectors provides a positive feedback effect on the others, which can lead to rapid saturation during a simulated accident. The social sector represents the agitation which follows any nuclear accident and the long term attention to forced outages, SALP scores, and government feedback which the social and governmental stakeholders experience. The strong positive feedback effects among each factor of social and government sectors is shown in Figure 2.8.

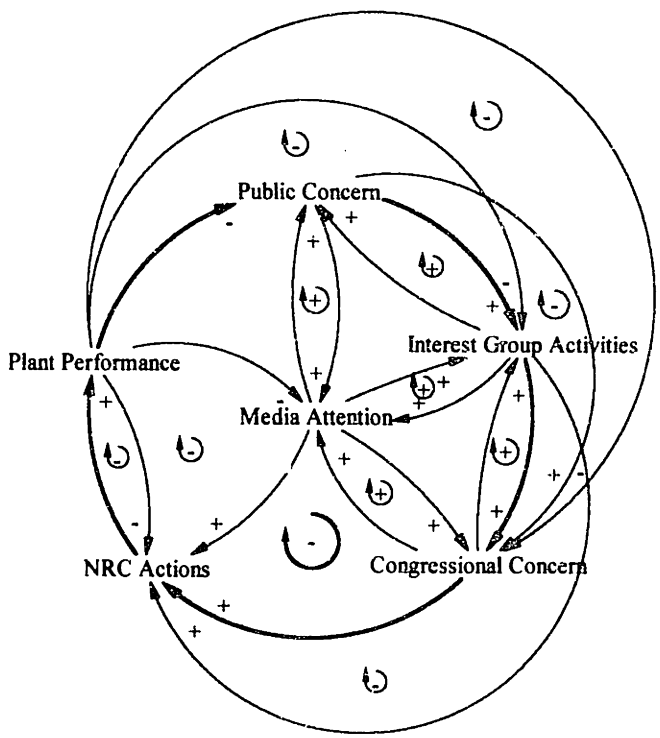

Figure 2.8 Casual Loop Diagram of Social and Government Sector

The negative feedback loop dominates the overall social and government sector. The public at large expresses concern over nuclear power plant safety. The media dominates as a public source of information. Public action occurs through interest groups which influence the government and utility.

2.3.1 Local and National Public Concern (view 32, 33)

2.3.1.1 Description

Local public concern, *Public Opposition[LO]*, represents the public in the community served by the nuclear power plant. Local public concern is capable of being much more variable than national public concern because of the reactor's operating history, local goodwill efforts, and local politics. The local public concern has a direct impact on the Public Utility Commission (PUC), local media, stock prices, and interest groups. Local public concern is heavily influenced by national public concern, but the effect of an accident at another plant is not as great on local public concern if the local utility has performed well.

National public concern, *Public Opposition[NA]*, represents the public at large. It does not change as rapidly as local public concern. However, its effect on the finance of the utility can be greater because of the possibilities for increased inspections, regulations, interest group lawsuits, and media activities.

2.3.1.2 Computer Presentation

This sub-sector was unified and simplified with a subscript variable, *XPublic Concern: NA, LO*. The variable names using this subscript variable are shown in Table 2.5 and stock - flow diagram is appeared in Figure 2.9.

Table 2.5 Variable Names of Public Concern Sector

Variable Name	*Variable Type*	*Units*
Public Opposition	stock	concerns
INT Public Opposition	initial value	concerns
Chg pub opp	flow	concerns/week
Fading pub opp	flow	concerns/week
bound PO	converter	concerns
time to chg opp	converter	weeks
ind pub opp	converter	concerns
net effect	converter	dimensionless
D ave desensitization	converter	weeks

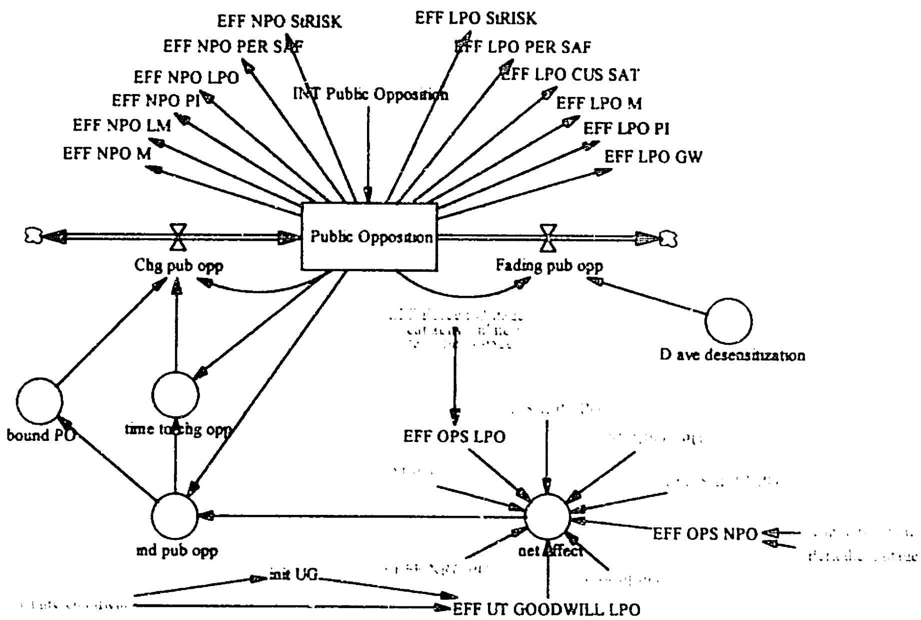

Figure 2.9 Vensim Diagram of Public Concern Sector

2.3.2 Media (view 34)

The media monitors interest group activities, government reaction, congressional concern, public concern, and utility operations. Based on these measures, the media produces reports and follow-up stories that influence the concerned groups again. This effect can cause a strong positive feedback (L.D.Simon, 1995, p47).

2.3.3 Interest Groups (view 35, 36)

Anti-nuclear interest groups are constantly at work monitoring utility operations, government actions and public concern. These groups need funding to operate. It is the primary driver of group actions. Although the financial resources limit group actions, nuclear events directly affect the rate, efficiency, and timing of such expenditures of the group. There exist two sources of funding such as private foundations and public support. Especially, public support is directly coupled to public concern. As public interest grows, financial donations to support group actions increase. These contributions improve their ability to wage lawsuits, demonstrations and lobbying efforts. These interest group actions affect public concern, congressional concern, media attention and NRC actions. In some cases, these groups also have considerable influence on the PUCs.

2.4 Government Sector

The government sector concerns the actions of the national government. It includes the NRC, Congress, and SALP ratings sub-sector. The causal relations in the government sector are shown in Figure 2.8.

2.4.1 NRC (view 37 - 39)

Since government oversight falls to the Nuclear Regulatory Commission (NRC), all efforts at guiding government nuclear policy ultimately target NRC. Because the NRC seeks safety in nuclear operations, NRC concerns have influence on plant performance. Not only do accidents and major events cause NRC concern to rise, but also any information which indicates a higher probability of such an occurrence increases NRC concern. NRC policies, and perceptions of such policies, affect the interest of various groups associated with the nuclear industry. Because of this, several groups actively seek to alter NRC policy by presenting different perspectives on NRC actions, utility performance, and operation consequences.

The NRC controls inspections, regulations, and information transmission between utilities. After an accident, the NRC increases investigations, research, and regulation production. Direct effects on a utility are mandatory inspections, worker distractions due to NRC inspection work, and increased workload in the information sector This sub-sector provides regulators with an opportunity to gauge effects of new regulations and inspections. The NRC actions work to appease Congress, media, the public and interest groups.

The utility can influence the NRC by investing in regulation abandonment, conducting its own inspections, or improving its SALP scores. The model provides a good method for testing the return on investment in each of these areas (L.D.Simon, 1995, p48).

2.4.2 Congress (view 40)

The legal mandate for government involvement in the nuclear industry originates in the Congress. It writes the laws which create both regulations and regulators. Consequently, Congress exhibits much influence upon the industry both directly in laws passed and indirectly through the commentary of individual lawmakers (C.K.Eubanks, 1994, p40).

Congressional concern is influenced by public concern, media, interest group lobbying, utility lobbying, NRC responses and utility performance. As public concern increases, the number of concerned lawmakers increase. This increase directly affects the NRC by influencing them to conduct more investigations and write more regulations. Congressional concern naturally decays as other issues enter the political field (L.D.Simon, 1995, p48).

2.4.3 SALP (view 41)

The Systematic Assessment of Licensee Performance (SALP) sub-sector represents the calculation of the utility's SALP score. This score determination is done by the NRC and is based on Engineering, Maintenance, Operations, and Support factors. The engineering score is based on engineer workload and quality design specifications achieved for parts. The maintenance score is determined by mechanics workload and broken equipment. Operations is based on training forced outage frequency and operator astuteness. Support is based on manager workload and information usage. The model does not calculate all of the factors that enter into SALP scores, such as operator drill performance, security, or safety analysis performance. These additional factors are assumed to average and have the effects of reducing the range of the SALP score somewhat.

2.5 Information Sector

The information sector was developed in order to represent the plant's processing of information, and the associated costs and benefits of information use. The information sector concentrates upon the information exchange aspects of the nuclear industry, but is able to affect performance, safety ratings and financial costs. Essentially, this sector helps to reduce plant problems and breakdowns through procedure revisions, training, and plant modifications.

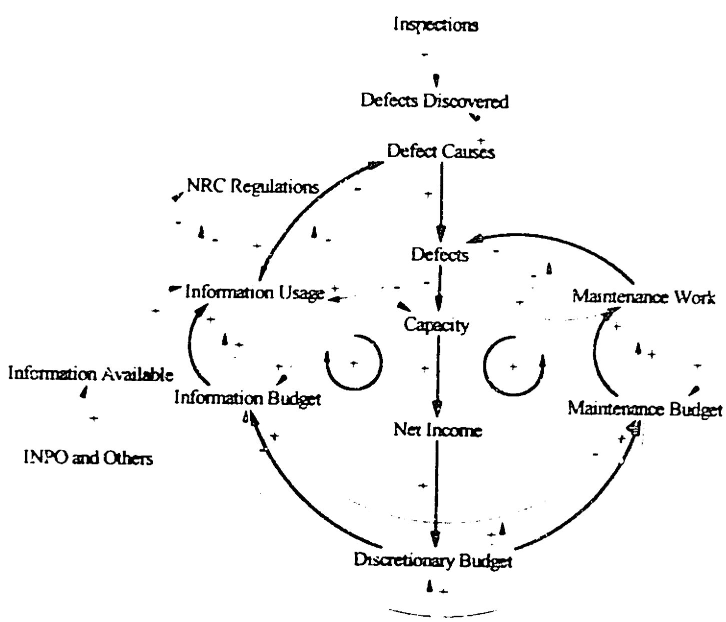

Figure 2.10 Causal Loop Diagram of Information Sector

The main causal relationships between information usage and capacity within the plant are shown in Figure 2.10. There are two main positive loops, which shows the effect on capacity of information usage and performing maintenance work. A positive loop related to information usage can improve plant capacity by reducing defects which cause breakdowns in plant equipment. Defects are diminished because their causes are reduced in the plant by taking corrective actions in the information sector. The effectiveness of information usage in the model is driven mainly by the number of engineers and managers allocated to performing the information work. Another key use of professional staff in the plant is a job review and approval in the maintenance sector. The allocation of the budget between maintenance and information personnel is the variable that controls and limits these two positive loops. Additionally, if information staffs are effective in the process of reducing the number of NRC regulations put on the books, unnecessary maintenance work can be reduced. This can be positively effect capacity, because less equipment is taken down during the unnecessary work. The information sector is composed of 11 sub-sectors.

2.5.1 Industry Events (view 42, 43)

The main source of information is made available from events that occur at other nuclear power plants. It is these events that produce information about problems in the industry. These problems come from various sources, such as operations, training, equipment, and maintenance. Events classified by the NRC event classification levels are unusual events, site alerts, and site emergencies. Additionally, there is an exogenous major event, which is defined as an event as threatening as TMI. In this sector, the total number of identified problems from the four different types of event occurrences is determined. The identified problems will be sent to the various organizations for analysis and reporting. A problem can be thought of as pages of issues identified at the plants.

2.5.2 Industry Problem Reporting (view 44)

2.5.2.1 Description

After the problems are identified at the plants, they are sent to various national organizations for review. These organizations process the information into reports and notifications that the utilities use in their information processing systems. This sub-sector includes problem reporting, and distributing problems to the organizations. There are four national and international organizations, such as EPRI, NRC, WANO and utility vendors.

2.5.2.2 Computer Presentation

The processes of problem analysis and research projects of these four organization are unified by using a subscript variable, *Xprob Reporting: VEN, NRC, EPR, WAN. VEN, NRC, EPR*, and *WAN* indicates utility vendors, NRC, EPRI, and WANO as mentioned before. The stock - flow diagram about this is represented in Figure 2.11. The variable names using these vectors is also shown in Table 2.6.

Table 2.6 Variable Names of Industry Problem Reporting Sector

Variable Name	*Variable Type*	*Units*
Research in Progress	stock	reports
INT Research in Progress	initial	reports
Research initiation	flow	reports/week
Research completion	flow	reports/week
D time to completion	converter	weeks

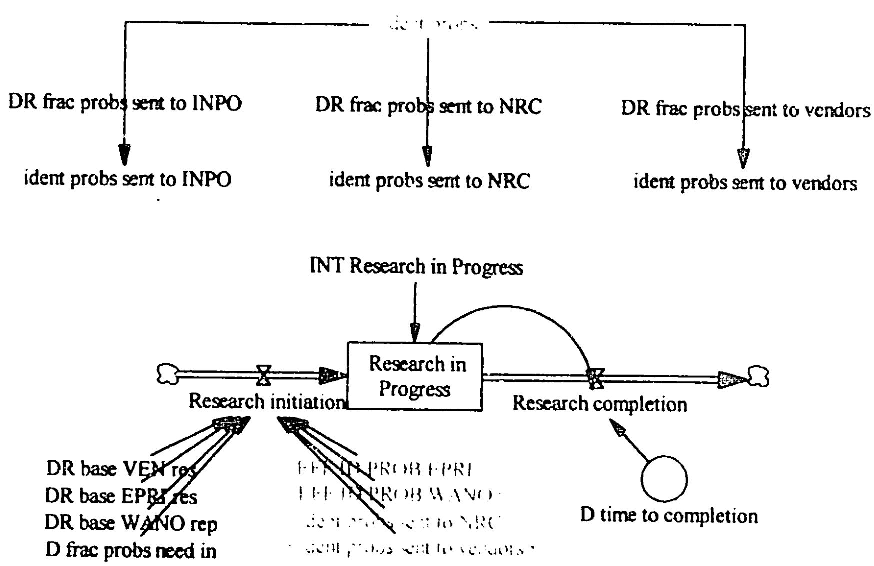

Figure 2.11 Vensim Diagram of Industry Problem Reporting Sector

2.5.3 INPO (view 45 - 47)

This sub-sector shows how INPO processes problems through its SEE-IN network. Because INPO is the most effective and influential information exchange organization in the industry, it is modeled separately. It includes the problem reviews and report productions (Rees, 1994, p127).

INPO produces three different types of report in this sub-sector. They are; SEN- Significant Event Notification. These alert plants as promptly as possible that a significant event has occurred. Further information may be followed on SER- Significant Event Report. These provide a brief description of a significant event or problem and comments on why it was significant. SOER- Significant Operating Experience Report. When INPO recommendations result from evaluations of the identified problems, they are incorporated into a SOER. A SOER is prepared for problems that require the most focused utility attention (Boston Edison, 1992, p6).

2.5.4 Report Screening (view 48)

All reports coming into the utility, are quickly screened by an available information engineer. Screening is performed to determine whether the problems addresses in the reports are applicable to the plant or have been analyzed previously. SOER's are screened separately from the other reports because the information in them is usually of high importance to the utility, and needs to be screened as quickly as possible (L.D.Simon, 1995, p82).

2.5.5 Problem Screening (view 49)

This sub-sector provides the ability to study internal plant problems. When defects are discovered, they are fixed through the maintenance work. With the information sector, the plant studies what causes the defects, and takes corrective actions to prevent them from occurring again. There are two screenings in this process. Initially, the problems are screened by the head shift nuclear engineer (usually called the Nuclear Watch Engineer or NWE), and then screened by the technical group designated for reviewing in-plant problems. The NWE screening is included because some problems dictate the initiation of immediate corrective actions.

2.5.6 Evaluation (view 50)

Once reports and in-plant problems are screened for applicability or redundancy, they are sent to engineers to be evaluated further. These evaluations consist of reviewing plant-specific design, procedures, practices, and operating history to identify weaknesses or vulnerabilities that could result in similar events at the plant. Before any further actions can be taken, the evaluations are then validated by managers for correctness.

2.5.7 Corrective Action Process (view 51, 52)

2.5.7.1 Description

Corrective actions are taken when evaluations determine that changes must be made in the plant to prevent the problems from surfacing. Three types of corrective actions are taken within the plant: procedures are written or revised, new training methods and procedures are created, and plant modifications are made. New and revised procedures can help to reduce defect causes because workers have more complete and less erroneous procedures available for maintenance work and operations. Enhancing worker training makes staff more knowledgeable and less error prone in the work they perform. Modifications increase plant specifications for materials and reduce defects in completing new scheduled work orders.

This sub-sector has two major processes. In the first, a manager assigns an appropriate engineer to perform the corrective actions. The second process is the completion of the corrective action. This may include writing a procedure, creating and planning a modification, or reviewing and changing training procedures. These are performed by engineers, and reviewed for correctness by managers before they can effect the plant (L.D.Simon, 1995, p95).

2.5.7.2 Computer Presentation

These processes of performing the corrective actions were reproduced from iThink utility model with a subscript variable, *Xcorrective Action: PRO, MOD, TRA*. Here, *PRO* represents the process of writing a procedure. *MOD* indicates the process of creating and planning a modification. Finally, *TRA* represents the process of reviewing and changing training procedures. Table 2.7 shows variable names using this subscript variable and the stock - flow diagram of this sub-sector reproduced is shown in the Figure 2.12.

Table 2.7 Variable Names of Corrective Action Process Sector

Variable Name	*Variable Type*	*Units*
CA in Progress	stock	corrective actions
INT CA in Progress	initial value	corrective actions
CA Waiting for Validation	stock	corrective actions
INT CA Waiting for Validation	initial value	corrective actions
CA change	flow	corrective actions/week
CA cmplted	flow	corrective actions/week
CA incorrect	flow	corrective actions/week
CA validated	flow	corrective actions/week
frac CA	converter	fraction
frac CA correct	converter	fraction
adj time to comp CA	converter	weeks
time to comp CA	converter	weeks
adj time to val CA	converter	weeks
time to val CA	converter	weeks

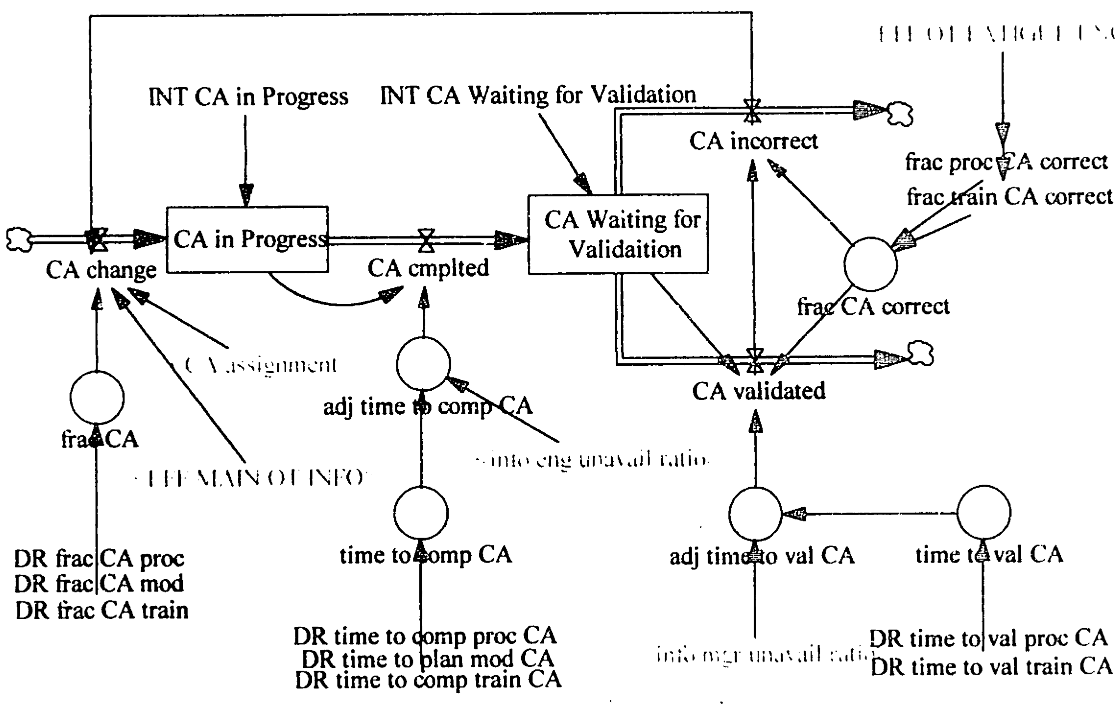

Figure 2.12 Vensim Diagram of Corrective Action Process Sector

2.5.8 Interactions with NRC (view 53, 54)

This sub-sector provides some of a nuclear power plant's interactions with the NRC for new regulation development. Nuclear power plants include information groups to oversee the NRC regulation process. These groups perform technical reviews of regulations under development at the NRC, interact with NEI for this development, and perform extensive evaluations of regulations impacts on the plant. The developed new regulations are first given to managers to assign technical reviews for regulations under development. Sometimes, concerns about regulations impact are brought to surface at the utility. These concerns are brought to the NRC through the NEI, who helps work with the utility to modify or get rid of the regulations. Once regulations are put on the books at the NRC, the plant will again review them and follow through on inspections, material specification changes, and corrective actions they outline (L.D.Simon, 1995, p101).

2.5.9 Information Labor (view 55)

This sub-sector calculates the information engineer and manager unavailability ratios that are used to adjust the numerous time delays in the information process. The stocks of information being screened, evaluated, and undergoing corrective actions are bought into this sector to calculate the amount of work to be done in the information sector. *Eng unavail ratio* and *info mgr unavail ratio* are the ratios of work to be done in the information sector to the amount of information work completed.

2.5.10 Information Learning Curve (view 56)

The most influential information use is its effect on reducing the causes or precursors of defects within the plant. Reducing defect causes helps to increase plant performance and improve safety. Both procedural and training corrective actions work to do this. More complete and correct procedures give mechanics, operators, and planners better guidelines for performing work that affects performance and safety. Training helps to make workers more informed, efficient and less error prone in their actions. Both of these effects can be thought of as reducing defect causes. In the nuclear plant sector, there are few direct places to make improvements for procedure training changes, so a learning curve was added to reduce defect causes from information learning (L.D.Simon, 1995, p111).

2.5.11 Information SALP Effect (view 58)

This sub-sector calculates the direct effect of using information on SALP score. Because it could improve performance and safety of the nuclear power plant, the NRC believes using information is a sign of good management behavior. For this reason, if the reports are analyzed correctly, the NRC will increase parts of the SALP score. This sub-sector tracts the number of available reports and the reports/information that are abandoned because of lack of manpower. The ratio of reports completed to total reports, *report analysis ratio*, is used in a converter that effects the SALP score in the nuclear plant sector.

2.6 Financial Resources Sector

The financial resources sector develops the relations which lead to limiting utility financial resources. In this sector, how public opposition, PUC (Public Utility Commission) decisions, or increased regulation affect the utility's ability to budget for safety is determined. This sector includes all aspects of utility financial operations such as accounting, capital markets, PUC and competition, etc. This sector is composed of eight sub-sectors. The main causal loop of this sector on utility's equity is shown in Figure 2.13.

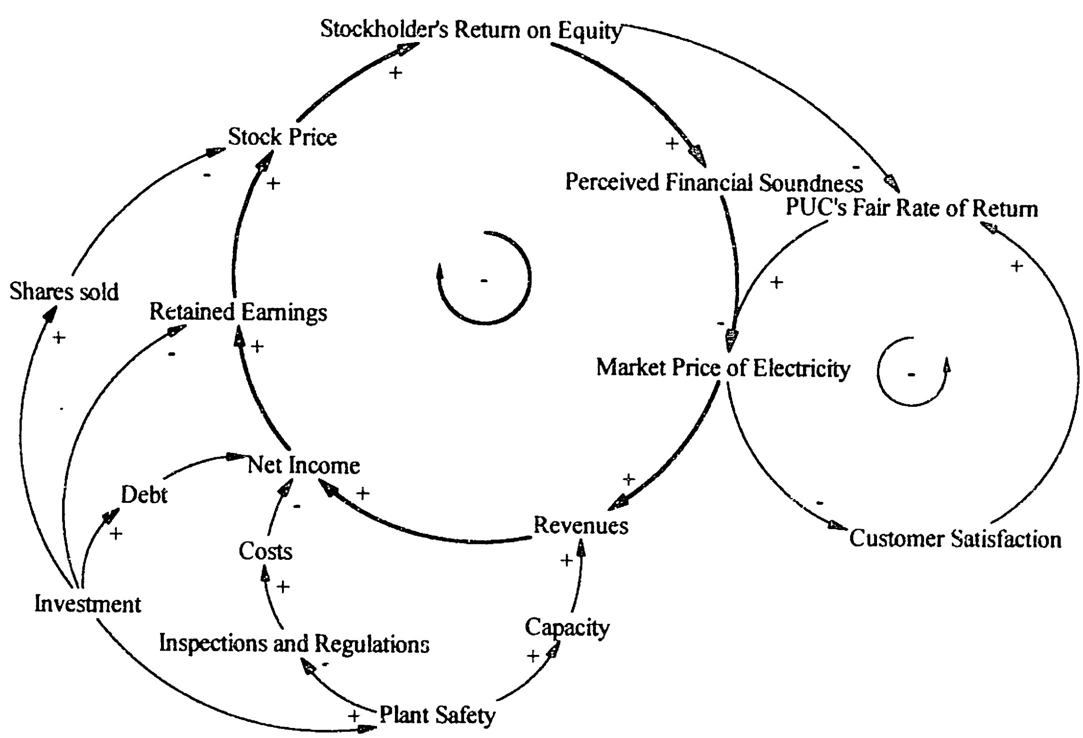

Figure 2.13 Causal Loop Diagram of Return on Equity in the Financial Resources Sector

There are two negative loops which have an effect on balancing the relationship between PUC's fair rate of return and stockholder's return on equity in this diagram. The PUC controls the negative feedback loop limiting the stockholder's return on equity to a fair return in exchange for the utility's guaranteed delivery of electricity.

Stockholder's return on equity positively affects perceived financial soundness. Under regulation, an increase in perceived financial soundness causes the utility to lower the market price of electricity which is based on PUC's fair rate of return. If the market price is lowered, revenue is going to drop, which causes net income to decrease. As net income drops, dividend and retained earnings decrease. Decreasing retained earnings and dividends causes the stock price to drop which causes the stockholder's return on equity to drop.

Secondly, as safety improves, capacity improves overall since less equipment is broken and customer satisfaction is improved as the local public is less concerned about the utility's operation. All these effects can have the overall effect of increasing net income by reducing costs and raising revenue.

2.6.1 Internal Finance (view 59 - 63)

This sub-sector determines the cash flows and the overall balance sheet. Costs are summed each week and subtracted off of revenues to determine the gross margin. Investment, property taxes and then income taxes are subtracted off of the gross margin. The remaining, net income minus dividends are forwarded to retained earnings. The retained earnings absorb the remaining cash after all other expenses are complete. The weekly revenues are generated based on *produced revenues*, which is earned from power produced in the plant itself and *bought power revenues*, which is earned from bought power. They flows into *Liquid Assets* as cash, but costs flow out of *Liquid Assets*. Costs include O&M costs and capital costs, which are debt payments. O& M costs are determined by adding all of the individual weekly costs together. Investment by the utility can be made by improving the quality of parts and design or by buying all new equipment. Taxes include property taxes and income taxes. Dividends are determined by multiplying *net income* by the utility's *dividend factor*.

2.6.2 PUC (view 64 - 66)

The PUC (Public Utility Commission) is influenced by customer satisfaction, utility performance, interest groups, and political ideas in determining a perceived prudence of the utility. This prudence translates into an allowed return on equity and an allowed rate base. Once the allowed return on equity is determined, it is translated into a cash value and compared with the utility's requested return. Combined with pass through costs such as fuel costs and NRC regulation costs, a PUC price is determined after a delay to account for the time between rate case proceedings. In this sub-sector, *PUC Rate* is the maximum legal cost per kilowatt-hour that utility may be charged based on the utility's fair rate of return.

If there is competition, this price represents only an allowed price. The price the utility must actually charge is a competitor's price, which can be multiplied by a small increase based on proven reliable service. Additionally, the PUC can change from benevolent to evil in the eyes of the utility based on political changes.

2.6.3 Budgeting and Allocation (view 68, 69)

This sub-sector would be used most frequently for managers to test spending decisions to analyze strategic decisions. Utility operations are controlled through allocation of dollars. One can decide to spend more money on inspections, capital equipment, information, personnel, goodwill or lobbying.

The discretionary budget which is divided into various spending pieces is determined by subtracting desired weekly profit and required cost from the week budget. Based on allocation, the maximum allowed number of maintenance workers, engineers, planners, and managers is determined. Also determined is the amount of the budget spent on discretionary budget, *frac labor bud alloc disc insp*. Additional spending decisions are made in training, lobbying, layoffs, dividends, parts, and overall cutbacks.

2.6.4 Stock (view 69, 70)

This sub-sector represents the stock market, capital costs and the utility's ability to raise equity through sales of shares. The stock market is represented by a Capital Asset Pricing Model. The risk of investing in the utility is compared to Treasury Bills. This results in a cost of capital, which is the required return on equity by an investor. This cost of capital is compared to the present value of estimated future cash flows of dividends to estimate a stock price. Combined with random variations and economic effects, this estimated stock price is converted into daily stock price. Comparing book value of the utility with daily stock price determines whether the utility can raise equity or not. If it can sell shares to raise equity, the utility maintain a 40% ratio of equity to debt.

The beta used in the variable names means the relative risk of investing in the utility. This risk is compared to the interest rate of zero risk securities such as T-bills and relatively risky items such as the rest of the stock market to obtain the stock discount rate. This rate is the required interest rate the stock should pay to compensate investors for overall risk.

2.6.5 Bond Rating Institutions (view 71)

Bond raters constantly monitor the financial position of utilities to determine their ability to repay long-term notes. The bond rating is on 1-12 scale from default, CCC to AAA+. In this sub-sector, the indicated bond rating, based on current financial elements, is driven from several factors based on financial indicators which bond rating institutions use to rate companies. The bond rating is delayed by the interval between doing bond rating analysis. The Credit Agency's Perceived Financial Soundness is adjusted to fit on a 1 - 12 scale. (Duff and Phelps Credit Rating Co., 1994)

2.6.6 Economic and Random Effects (view 72)

This sub-sector is the optional sector which inserts recessions, interest rate hikes, inflation and random effects onto the utility. It is usually off with inflation set to zero to facilitate interpretation of the model.

2.6.7 Perceived Financial Safety (view 73)

This sub-sector represents an investor's perceived risk of losing investment due to a major accident at the nuclear power plant. This risk influences the total risk of investing in the utility and affects the bond rating. It is determined by monitoring operations, SALP scores and forced outage frequency. Risks due to the PUC and economy are determined in the stock sector (M.K.Turek, 1995, p68).

2.6.8 Debt (view 74)

The utility manages cash shortfalls and capital investments by financing 60% through long term debt. Since so much debt is incorporated during construction of the plant, approximately 70% of costs go to debt payments in the model. If a utility consistently overspends, it will enter a death spiral of debt (M.K.Turek, 1995, p68).

Chapter 3

3.1 Sensitivity Analysis of The Model

The Nuclear Utility Model is not precise enough to make exact predictions of future behavior. This is why many of the 1,200 variables used in the model have not been validated with data from the industry. Because of this uncertainty of the data, the model output provides only a general guide of utility behavior, not an exact tool for managerial decisions. The variables, therefore, are required to be checked for their validity prior to gaining the precise data from the utility, and to be analyzed for identifying what variables have the potential to alter the model's behavior mode. This analysis of variables plays a critical role in developing the model which represents more accurate behavior. Sensitivity analysis is used as an analytical tool giving such intuition in this thesis.

Sensitivity analysis can be defined as the study of model responses to model changes. Here, it means simulating the model with the different assumptions about the constant variables, namely parameters. The sensitivity analysis results about each of parameters will be analyzed and discussed in this chapter. A few important variables will be discussed further in detail and presented in comparative graphs over time.

3.1.1 The objectives of Sensitivity Analysis

The most focused purposes of the sensitivity analysis for the Nuclear Utility Model are to test the effects of uncertainties in the parameters and generate insights about structure and behavior of the model.

Uncertainties in the nuclear utility model's parameter values may affect its response and thereby the conclusions derived from the model. As SD models tend to (1) include parameters for which no observations exist and (2) analyze such a long time span that most quantities tend to be variables rather than parameters with stable values, uncertainties in the model parameters are common. Typically, their values will be known within a range, but not precisely (J. Randers, 1980, p188). Testing alternative parameter values within the assumed range of uncertainty will provide the evaluation about the impact on the utility model conclusions.

An understanding of the relation between model structure and model parameters, on the one hand, and model's behavior, on the other, forms the basis for suggesting effective policies to deal with the problem at hand. We can discover which behavior modes the model can generate, identify which parameters whose precise values are of critical importance for the model's behavior, and identify the active and dormant parts of the model structure to establish a basis for finding the simplest recognizable structure that can generate the reference mode[4].

3.1.2 Type of Model Changes

Only parameters not including initial values of the stock variables were changed for sensitivity analysis. SD models are usually rather insensitive to parameter changes, as are real complex systems, because of dynamic properties in the negative feedback loop in the model structure which counteract any alternations imposed by parameter changes and generation of the model's behavior by a few feedback loops. There exists, however, the sensitive key parameters which greatly affect the model's behavior.

In order to find these key parameters, each parameter has been simulated three or four times respectively with the different assumptions. The changes of the values of each parameter are made with the plausible alternative assumptions. The values of any delay time or time constant usually are chosen between 50% and 200% - 300% of those values. For example, a constant variable, *DR mat acq delay* indicates the time it takes to get any extra materials for completing work orders. It has a base case value of 0.5 weeks and was simulated with three different assumptions such as 0.25, 1, 2 weeks.

The values of the other parameters, except delay times or time constants, are assumed approximately from 50% to 150% - 200% of those values. Of course, most assumed values of those variables are also assumed plausible enough to observe their sensitivity. For example, *DR equip per WO* with its base case value of 4 pieces of equipment per work order, which is the average number of pieces of equipment covered by a work order, was set to 3 and 5 pieces of equipment per work order. Even though

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[4] Reference mode is a clear idea of the behavior that one is trying to understand. It helps one set the boundary and level of aggregation of the model and keep a model simple. It shows a pattern of behavior through a graph.

small changes in its value assumed were made, each simulation produces good enough results to be analyzed.

Parameters which are simulated in this study are categorized into two groups. First, One is a kind of the variables whose value are required to be obtained from the industry. They can be obtained through the various ways such as interview with the workers and managers , etc. Their variable names begin with the capitals, '*DR*' such as *DR equip per WO*. The other type represents the test variables whose value are assumed for the simulation test. Their variable names begin with the capital letter, '*D*' such as *D layoff fraction*. The alternative assumptions of all parameter values in this study are shown in Appendix C.

3.2 Scope of the Sensitivity Test

This section presents how to perform the sensitivity test, assess the simulation results, and figure out a few important variables which affect the behavior and structure of the model. All constant variables from the utility model have been simulated several times. To show behavior responses, each of the simulation results will be shown in comparative graphs over time. Each simulation is run for ten years with a time step set at one quarter of one week. All simulations of one variable will be graphed together in order to provide a comparative view. The graphs of all variables simulated are also shown in Appendix C.

3.2.1 Indicator of Sensitivity Analysis

To test the model's sensitivity through varying parameter's values, the effect on *capacity on-line*, which is the most important indicator of performance and relative safety of the plant, will be considered. Since capacity on-line has a direct impact on net income which is the largest factor in determining the financial robustness of the utility, we do not have to analyze the effect of varying parameter's value on net income. Capacity on-line, therefore, is a good enough indicator to accomplish the sensitivity analysis.

3.2.2 Base Case

Whether or not the model is sensitive to a variable will be decided through the comparison of the base case with other simulation results within the graph. The base case refers to a case which has no parameter changes under a situation in which the utility operates in a stable social and political environment, stable financial environment, and no major accidents within the industry. The fundamental pattern of capacity on-line in the base case, which is a base line for sensitivity analysis, is presented in Figure 3.1.

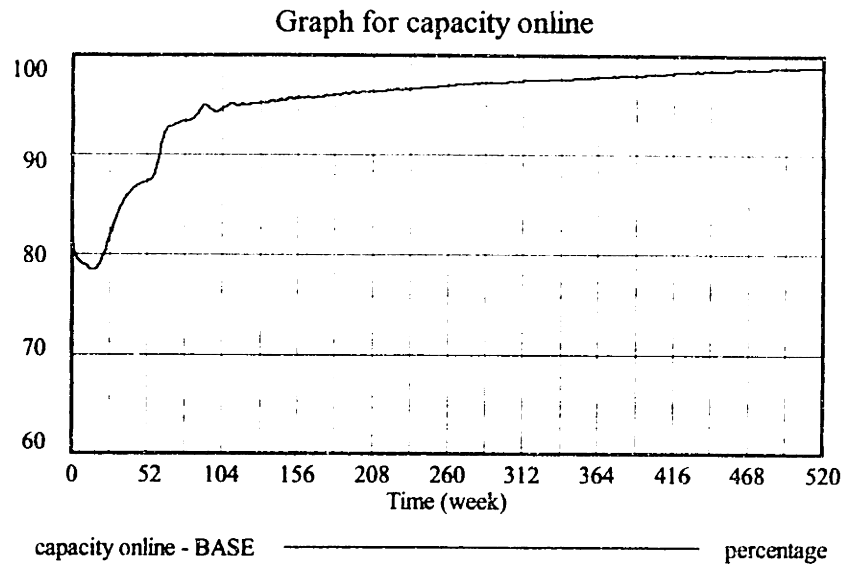


Figure 3.1 Graph for Capacity on-line with Base Case

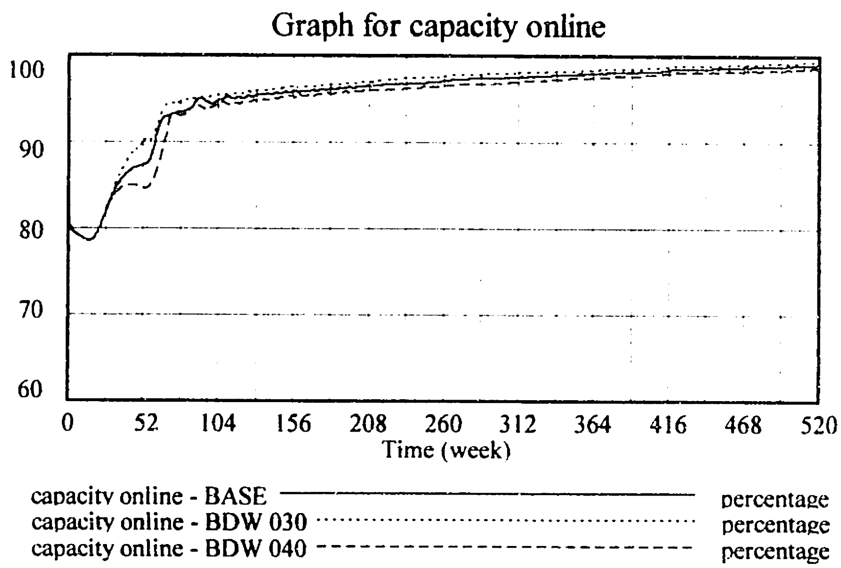
The first 104 weeks of each simulation will be called the 'initial transition period' throughout the discussions because the model is not yet in equilibrium. At 104 weeks, capacity on-line reaches the equilibrium state and then gradually increases by the end of simulation due to learning curve effects. This period is called the 'steady state period'. These two periods are considered together in this sensitivity analysis.

3.2.3 Modes of Sensitivity Analysis

First, whether a parameter has sensitivity to capacity on-line during the initial transition period is determined according to whether there are any changes of shapes in the graph for capacity on-line with comparison with base case during that period. There are two cases such as 'change' and 'no change' during the initial transition period.

During the steady state period, there are three different types of sensitivity; no change, numerical sensitivity, and behavior mode sensitivity. 'No change' is called when there is not any change of numerical values of the simulation results or exists only a numerical change which is too small to be figured out. It means the Nuclear Utility Model has no sensitivity to the different assumptions of the parameter.

Numerical sensitivity exists when a change in assumptions changes only the numerical values of the results, not the shapes of the graph of the results. For example, changing the *DR base defects from workmanship* from 0.35 defects/equipment in the base case to 3.0 or 4.0 defects/equipment numerically changes capacity on-line of the plant without any change of the pattern of capacity on-line over time. This is presented in Figure 3.2. The graph shows that even though there are changes during the initial transition period, there are only changes of numerical values in the model during the steady state.



Base case: DR base defects from wmanship = 0.35 defects/equipment
BDW 030: DR base defects from wmanship = 0.30 defects/equipment
BDW 040: DR base defects from wmanship = 0.40 defects/equipment

Figure 3.2 Graph for Capacity on-line with DR base defects from wmanship

When the pattern of behavior produced by the model is changed, behavior mode sensitivity exists. If alternative assumptions change the pattern of graph for capacity on-line, the utility model would exhibit behavior mode sensitivity. The graph which shows the changed pattern of capacity on-line with alternative assumptions of the average number of required equipment to proceed work order , *DR equip per WO*, will be shown in Figure 3.3.

Behavior mode sensitivity may be a serious threat to the adequacy and the utility of the model. If a variable exhibits the behavior mode sensitivity during the steady state period, this variable can be classified into a 'key variable' which can change the behavior mode of the model. If there are no change of the numerical values or the pattern of behavior during whole simulation periods, it means that the Nuclear Utility Model does not have any sensitivity to the alternative assumptions of a variable in the model. Since the variables of this type do not affect the results of the model for managerial decisions, they are not important parameters in obtaining the data in the industry. On the other hand, key variables need to get precise data in the industry. The analyzed results will be presented as the table in Appendix C.

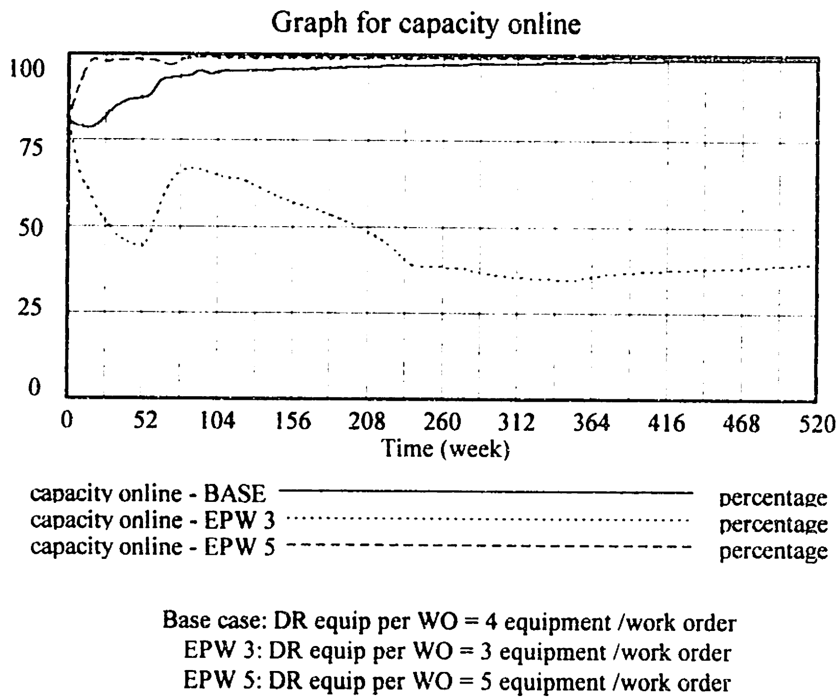


Figure 3.3 Graph for Capacity on-line with DR equip per WO

3.2.4 Key Variables

As the results of analysis, only the twenty-six variables among the total 221 constant variables were categorized into the key variables. These key variables are represented in the Table 3.1.

Table 3.1 The Key Variables of the Nuclear Utility Model

Variable	*Sector*	*Initial Transition*	*Steady State*
DR equip per WO	plant	Change	Behavior mode
DR customer demand	plant	Change	Behavior mode
DR frac dfct bdwn	plant	Change	Behavior mode
DR base dfcts ops per week	plant	Change	Behavior mode
DR mech experience cost factor	plant	Change	Behavior mode
DR mat acq delay	plant	Change	Behavior mode
DR unschd backlog time	plant	Change	Behavior mode
D layoff fraction	plant	No change	Behavior mode
D target weeks work	plant	Change	Behavior mode
DR planners per WO mat req	plant	Change	Behavior mode
DR frac eng info	plant	Change	Behavior mode
D eng layoff fraction	plant	No change	Behavior mode
DR maint rev per eng per week	plant	Change	Behavior mode
D mgr layoff fraction	plant	No change	Behavior mode
DR maint rev per mgr per week	plant	Change	Behavior mode
DR ave no reports per res proj	government	Change	Behavior mode
DR ave regulations sought per report	government	Change	Behavior mode
DR info learning curve fraction	information	Change	Behavior mode
DR HL waste mgt	financial	Change	Behavior mode
DR ops overhead	financial	Change	Behavior mode
DR unit $ fuel	financial	Change	Behavior mode
DR hrly cost labor	financial	Change	Behavior mode
DR annual fixed costs	financial	Change	Behavior mode
DR frac bud training	financial	Change	Behavior mode
DR mgr annual salary	financial	Change	Behavior mode
D desired return on equity	financial	Change	Behavior mode

3.3 Discussions of Model Behaviors

In this section, it will be discussed respectively for each of key variable why the model shows such a dynamic response to the alternative assumptions of them. The discussions will present how the interactions derived from different combinations of assumptions have influence on the dynamics of the model. Behavior and structure of the model is figured out through these discussions.

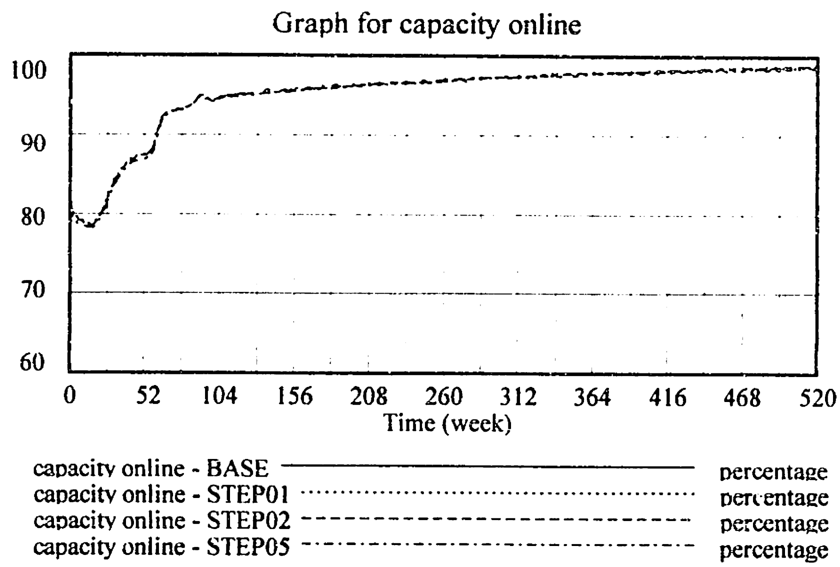
3.3.1 Time Step

The *Time Step* in the SD model represents an instant of time, which is the interval of time between calculations. In the real world an instant is infinitesimally small. In order for the simulation to conclude, the modeled instant can not be a real instant. Roughly speaking, as the value of a model's time step decreases, simulation accuracy increases, but the simulation takes longer to run. It is, therefore, necessary to check whether the simulation results are affected by the combination of different assumptions for the time step. The graph in the Figure 3.4 on the next page shows the sensitivity to the time step.

The time step does not affect the results of simulation for sensitivity test. The negligible difference between each simulation is due to the interactions made by variables whose equations use the time step, such as *DR base prob sa* and *DR base prob se*. *DR base prob sa* indicates the base probability for site alert and *DR base prob se* is the base probability for site emergency. These two variables directly change the number of identified problems due to event occurrences. The change of the number of identified problems affects the plant performance through the information process.

3.3.2 DR equip per WO

The variable, *DR equip per WO*, represents the average number of pieces of equipment covered by a work order. In base case, the value of *DR equip per WO* is 4 equipments/work order, and simulations for two different assumptions of 3 and 5 equipments/work order were also performed.



Base Case: Time Step = 0.25 weeks
STEP01: Time Step = 0.1 weeks
STEP02: Time Step = 0.2 weeks
STEP05: Time Step = 0.5 weeks

Figure 3.4 Graph for Capacity on-line with Time Step

The simulation results for *DR equip per WO* is shown in Figure 3.3 on page 60. It shows that the average number of pieces of equipment covered by a work order has a serious impact on capacity on-line. If *DR equip per WO* decreases, the number of new scheduled work orders created has to be increased. This is because a work order covers less pieces of equipment required to be taken down. Thus, this makes the number of work orders in progress increase. The increase of the work orders in progress requires more maintenance staff. However, since the maximum number of maintenance staff is limited due to limitation of budget allocated on mechanics, there is a shortage of manpower for maintenance. This causes an increase in defects, which causes pieces of equipment broken down. More pieces of equipment broken down leads to much capacity down.

Eventually, since *DR equip per WO* is the important variable which determines the amount of work, it is necessary to acquire more accurate data in the industry. Figure 3.5 shows the effect of varying the average number of pieces of equipment covered by a work order on identified defects.

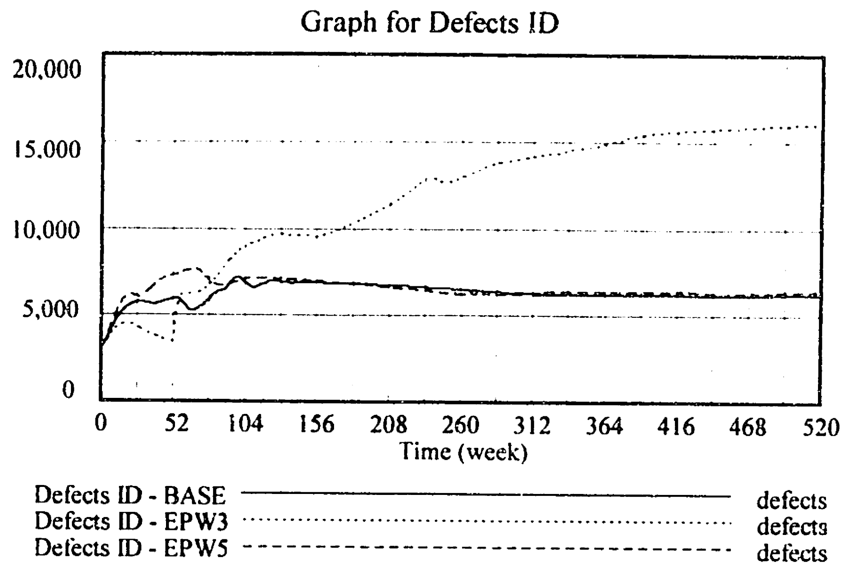
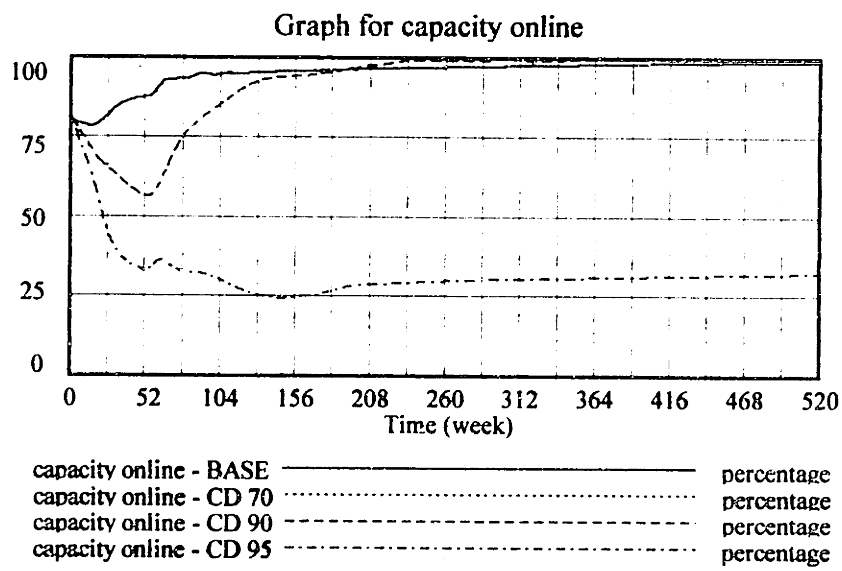


Figure 3.5 Graph on Defects ID with DR equip per WO



Base Case: DR customer demand = 80%
CD 70: DR customer demand = 70%
CD 90: DR customer demand = 90%
CD 95: DR customer demand = 95%

Figure 3.6 Graph for Capacity on-line with DR customer demand

3.3.3 DR customer demand

The variable, *DR customer demand*, is the level of customer demand for power, which it is quantified as a percentage toward to the plant capacity available. Four different simulations set to 70%, 80%, 90%, and 95% were run.

Figure 3.6 shows the effect of varying the percentage of customer demand on capacity on-line. When customer demand is less than customer demand of 80% in the base case, there is no reduction of capacity on-line. Because there is no power to be bought by the utility to make up for power not generated, the plant does not have to spend a supplementary budget. As customer demand increases over 80%, the power to be bought occurs. The plant should bear the additional costs for power to be bought. This causes decrease in the discretionary budget, which is the amount of money the manager can play with each week. Eventually, the reduction of discretionary budget determines the reduction of budget for maintenance work. Discretionary budget have a great impact on the various budgets such as personnel allocation, inspection, and training budget, etc. The tree diagram of uses of discretionary budget are shown in Figure 3.7 and the effect of varying customer demand on discretionary budget in Figure 3.8.

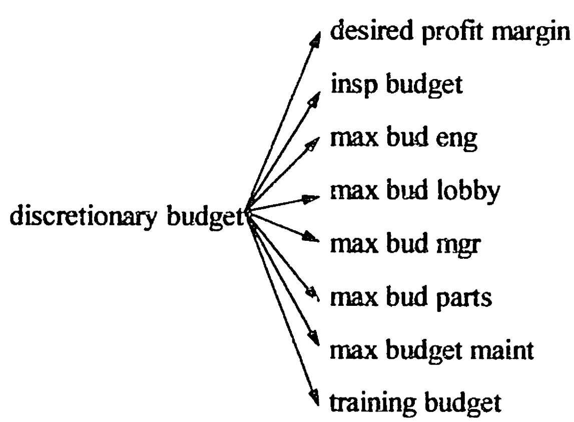


Figure 3.7 Tree Diagram of Discretionary Budget

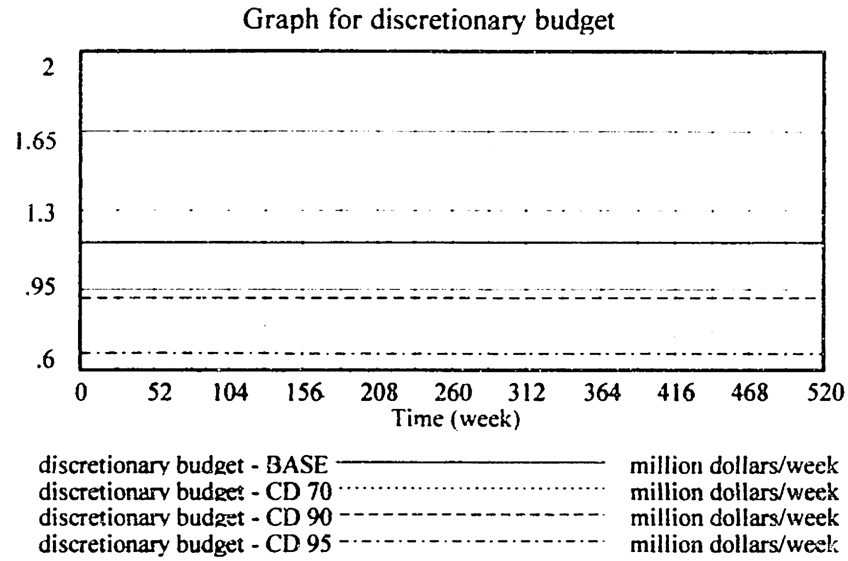
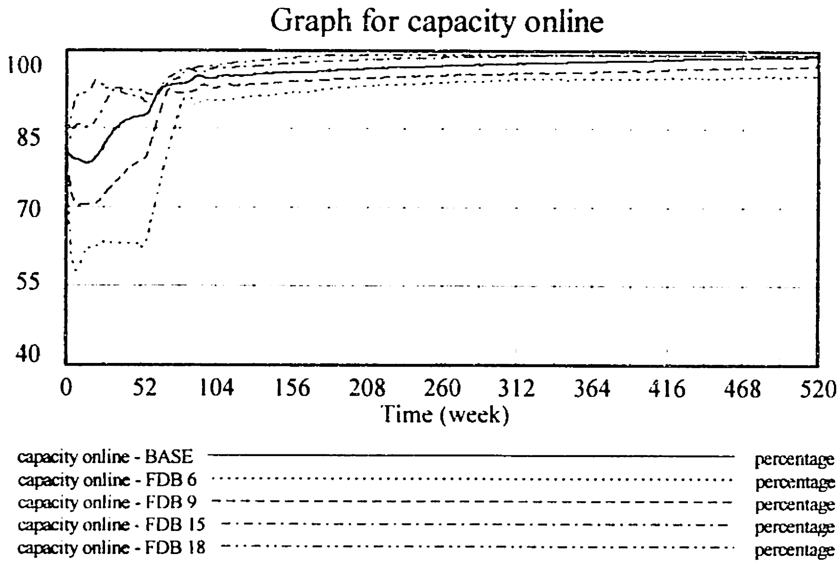


Figure 3.8 Graph for Discretionary budget with DR customer demand

With 90% case, decreased budget for parts causes the reduction in new defects determined from parts consumed. This decreases unidentified defects which cause on-line breakdowns. So, even though there are less maintenance staffs in 90% case, the model can overcome initial capacity down due to less maintenance staffs. But, with 95% case, the model can not overcome the capacity down. This is why the lack of maintenance manpower to maintain plant capacity affects the plant performance more than positive effect due to the reduction in unidentified defects.

3.3.4 DR frac dfct bdwn



Base Case: DR frac dfct bdwn = 1/12 equip breakdown/defects/week
FDB 6: DR frac dfct bdwn = 1/6 equip breakdown/defects/week
FDB 9: DR frac dfct bdwn = 1/9 equip breakdown/defects/week
FDB 15: DR frac dfct bdwn = 1/15 equip breakdown/defects/week
FDB 18: DR frac dfct bdwn = 1/18 equip breakdown/defects/week

Figure 3.9 Graph for Capacity on-line with DR frac dfct bdwn

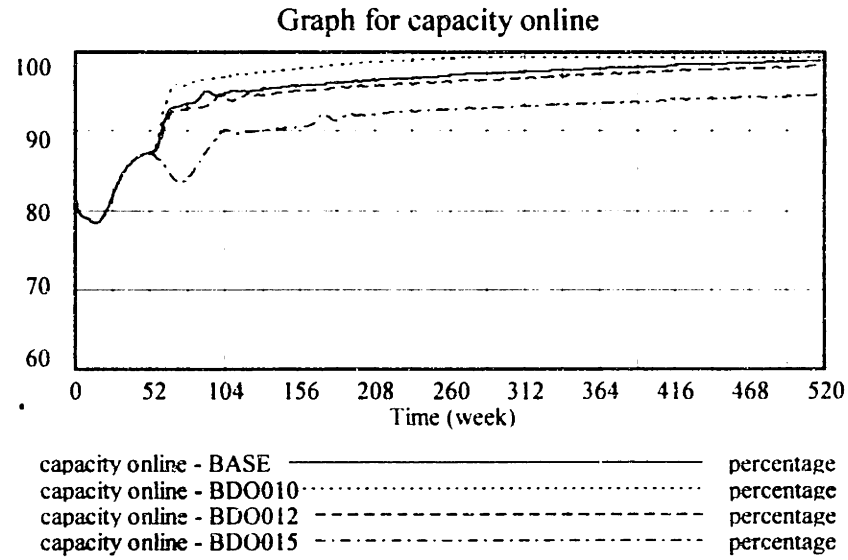
The variable, *DR frac dfct bdwn*, is the fraction of defects that cause breakdowns per week. All defects will cause breakdowns in 12 weeks if this fraction is 1/12. Five different simulations set to 1/6, 1/9/, 1/12, 1/15, and 1/18 were run.

The simulation results for *DR frac dfct bdwn* is shown in Figure 3.9. The larger is the fraction of defects that cause breakdowns per week, the larger is the reduction in capacity on-line. This is why *DR frac dfct bdwn* directly determines the number of pieces of equipment broken down. If denominator of *DR frac dfct bdwn* decreases, it means an increase of the fraction of defects that cause breakdowns. It leads to an increase of the number of pieces of equipment broken down. This causes more capacity down.

3.3.5 DR base dfcts ops per week

The variable, *DR base dfcts ops per week*, represents the base level of defects which result from wear and tear of normal operations. Four different simulations set to 0.1, 0.115, 0.12, and 0.15 * *(1-frac new equipment)*.

Figure 3.10 shows the effect of varying the base level of defects from wear and tear of normal operations on capacity on-line. As the value of base level of defects which result from operations increases, the number of defects unidentified or identified increases. This increases the number of pieces of equipment broken down or equipment taken down. Eventually, as the base level of defects from wear and tear of normal operations increases, the reduction in capacity on-line increases.



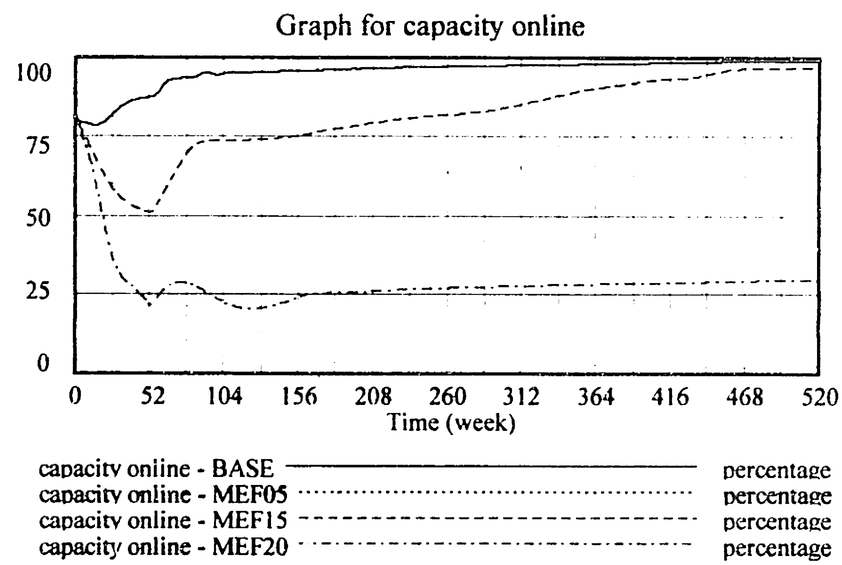
Base Case: DR base dfcts ops per week = 0.115 * (1-frac new equipment) defects/equipment/week
BDO010: DR base dfcts ops per week = 0.10 * (1-frac new equipment) defects/equipment/week
BDO012: DR base dfcts ops per week = 0.12 * (1-frac new equipment) defects/equipment/week
BDO015: DR base dfcts ops per week = 0.15 * (1-frac new equipment) defects/equipment/week

Figure 3.10 Graph for Capacity on-line with DR base dfcts ops per week

3.3.6 DR mech experience cost factor

DR mech experience cost factor is the mechanic's experience cost factor, which is the multiplier that managers can use to hire more experienced mechanics for more money. Four different simulations set to 0.5, 1.05, 1.5, and 2.0 were run.

Figure 3.11 shows the effects of varying the mechanics' experience cost factor on capacity on-line. As *DR mech experience cost factor* increases, manager should spend more money to hire more experienced mechanics. It means that the number of mechanics to be hired under fixed budget decreases. The plant, therefore, can not complete the maintenance work to maintain capacity due to the lack of manpower for maintenance. This causes capacity down.



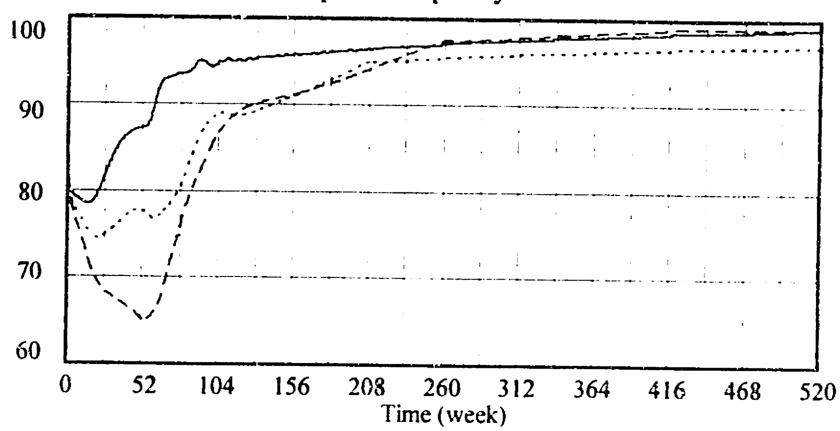
Base Case: DR mech experience cost factor = 1.05
MEF05: DR mech experience cost factor = 0.5
MEF15: DR mech experience cost factor = 1.5
MEF20: DR mech experience cost factor = 2.0

Figure 3.11 Graph for Capacity on-line with DR mech experience cost factor

3.3.7 DR mat acq delay

The variable, *DR mat acq delay*, represents the time delay that it takes to acquire material for scheduled and planned work orders that require materials. Three different simulations set to 0.5, 1, and 1.5 were run.

Graph for capacity online



Base Case: DR mat acq delay = 0.5 weeks
MAD10: DR mat acq delay = 1.0 weeks
MAD15: DR mat acq delay = 1.5 weeks

Figure 3.12 Graph for Capacity on-line with DR mat acq delay

Figure 3.12 shows the effects of varying the delayed time in acquiring materials on capacity on-line. During the initial transition period, two runs except base case show the big dips, which are caused by the delayed effect of completion of work orders requiring additional materials. These additional materials were unforeseen in the planning process or were not recognized as being required until work was under way. The delayed effect of acquiring materials has kept work orders waiting for being completed so long. This causes an increase of the number of work orders that are currently being worked on. Since in this state, the equipment is off-line, the number of pieces of equipment fully functional decreases. Eventually, capacity is reduced due to more equipment taken down.

3.3.8 DR unschd backlog time

The variable, *DR unschd backlog time*, indicates the time between noticing a piece of equipment begins to fail and the time when a work on unscheduled work orders is begun. This variable controls the flows of unscheduled work orders from unscheduled work orders waiting equipment, *Unschd Work Order[U3]*, into the category of the work in progress, *Unschd Work Order[U4]*.

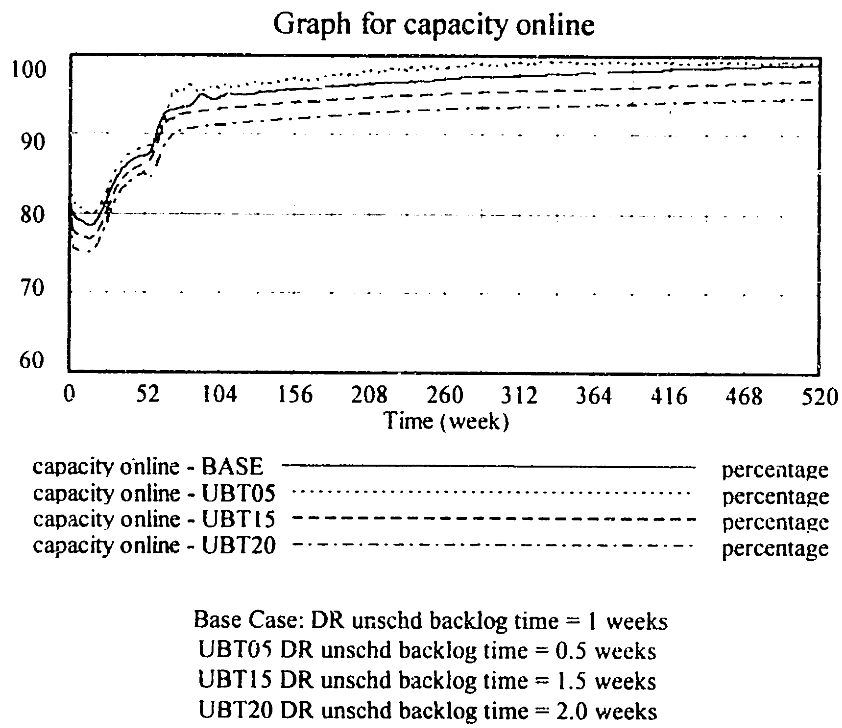


Figure 3.13 Graph for Capacity on-line with DR unschd backlog time

Four different simulations set to 0.5, 1.0, 1.5, and 2.0 were run. Figure 3.13 shows the effect of varying the backlog time for unscheduled work orders on capacity on-line. As the backlog time increases, it takes longer for work orders to flow into work in progress category. It means that equipment broken down should stay much longer until work on its repair is begun. Eventually, increase of the backlog time causes the number of pieces of equipment broken down to increase. Figure 3.14 shows the number of pieces of equipment broken down due to varying the backlog time for unscheduled work order.

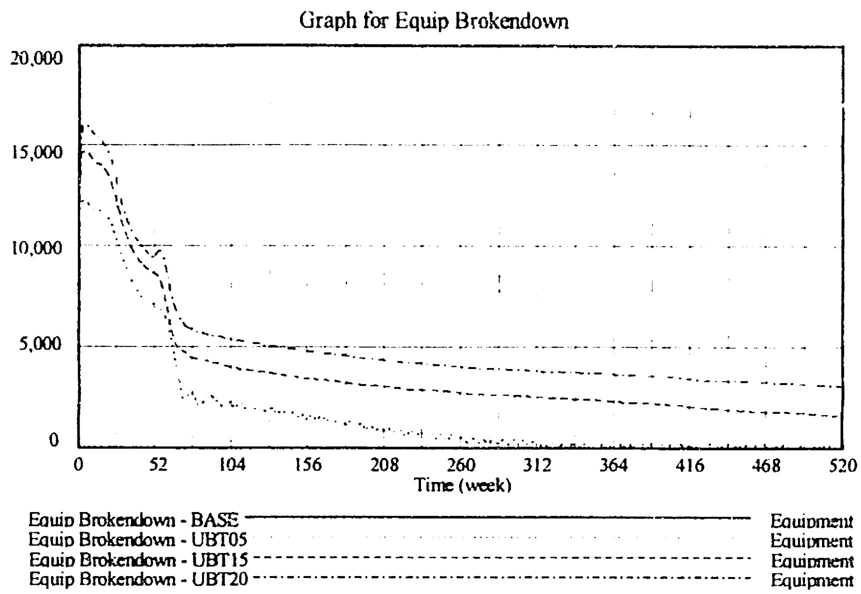
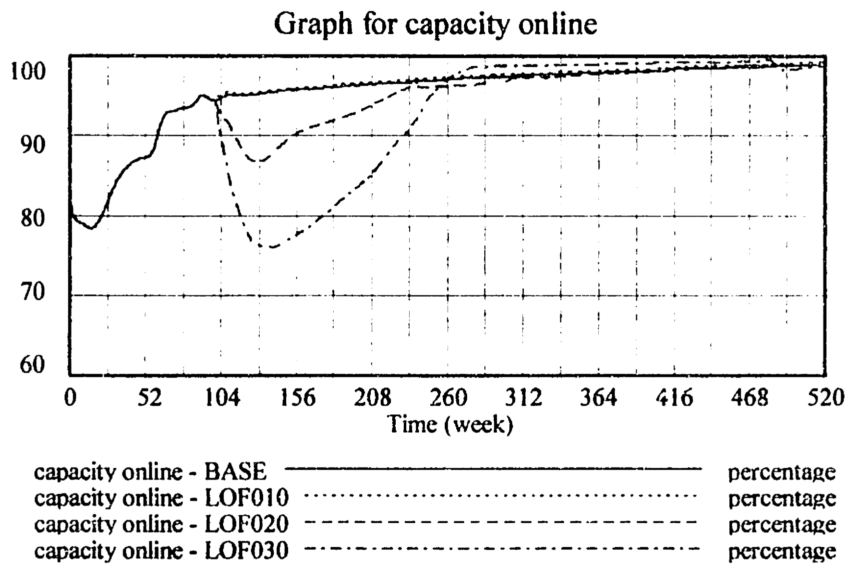


Figure 3.14 Graph for Equip Brokendown with DR unschd backlog time



Base Case: D layoff fraction = 0%
LOF010: D layoff fraction = 10%
LOF020: D layoff fraction = 20%
LOF030: D layoff fraction = 30%

Figure 3.15 Graph for Capacity on-line with D layoff fraction

3.3.9 D layoff fraction

The variable, *D layoff fraction*, is the fraction of maintenance staff laid off. The fraction of maintenance staff laid off was set to zero until week 100. At week 100, it was then set to 0%, 10%, 20% and 30%.

Figure 3.15 shows the effect of varying the number of maintenance staffs laid off on capacity on-line. There is no change of capacity on-line with the case of 10% layoff. With 20% case, the model shows the behavior mode sensitivity to the layoff fraction of maintenance staff. With 30% case, the model exhibits policy sensitivity[5]. Reducing the manpower for maintenance by a 20% layoff decreased capacity on-line of the plant. But, for a 30% layoff capacity increased. At week 260, capacity on-line of 30% case exceeds the one of no layoff case and 20% layoff case. This shows the reverse effect which is caused by changes in assumptions about model boundary.

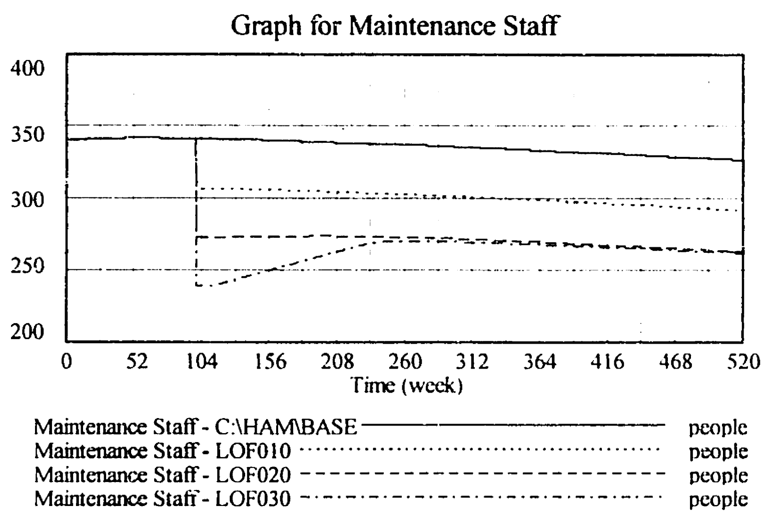


Figure 3.16 Graph for Maintenance Staff with D layoff fraction

Once the maintenance staffs are laid off at week 100, there are big drops in capacity on-line. This is caused by a lack of manpower for maintenance works. The lack of

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[5] Policy sensitivity exists when a change in assumptions reverses the desirability or impacts of a proposed policy. It tends to arise when one considers changes in assumptions about model boundary and time horizon. Obviously policy sensitivity is far more important than numerical sensitivity.

manpower for maintenance works causes increases in defects unidentified. This causes an increase of the number of pieces of equipment broken down. The plant, therefore, focuses by far on repairing the equipment broken down, not PM. Especially, work load and overtime hours of mechanics for unscheduled works increases. As the work load and overtime hours of mechanics increases, the plant increases capacity. But, since excessive overtime gradually causes fatigue and reduces productivity, the plant should hire more mechanics to maintain capacity. In case of the big lack of manpower for maintenance works by a 30% layoff, since workers overworked, more mechanics should be hired. In this model, if overtime exceeds 10 hours per week, two mechanics are hired with a time delay in hiring. The overtime of 30% layoff case exceeds 10 hours per week from week 110 to week 220. As a result, the plant maintains almost the same level of manpower of the case of 20% layoff after week 230. But, since overwork of mechanics continues after reaching at the same level of manpower of the case of 20% layoff, the plant maintains higher capacity due to no pieces of equipment broken down. The effect of varying layoff fraction on maintenance staff is represents in Figure 3.16, and the effect on the indicated overtime of the maintenance staff is shown in Figure 3.17. Figure 3.18 shows the effect on equipment broken down.

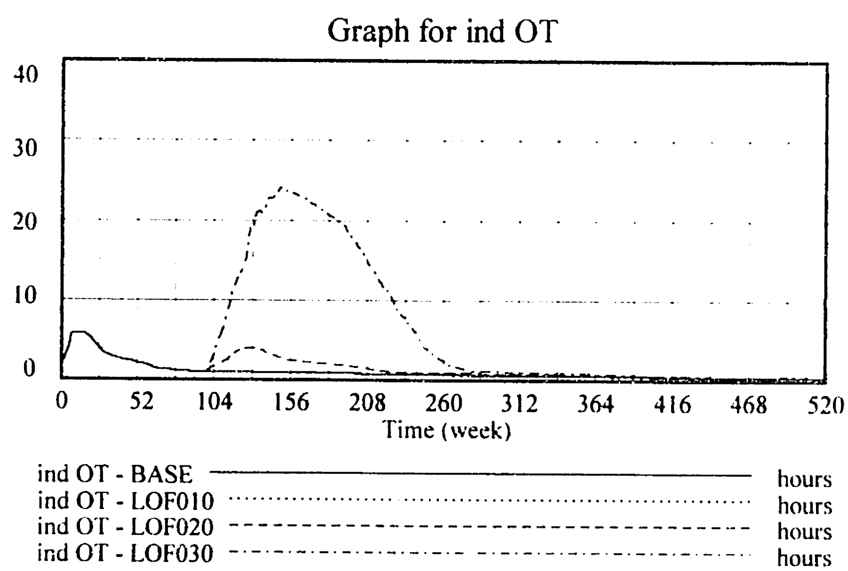


Figure 3.17 Graph for Indicated Overtime with D layoff fraction

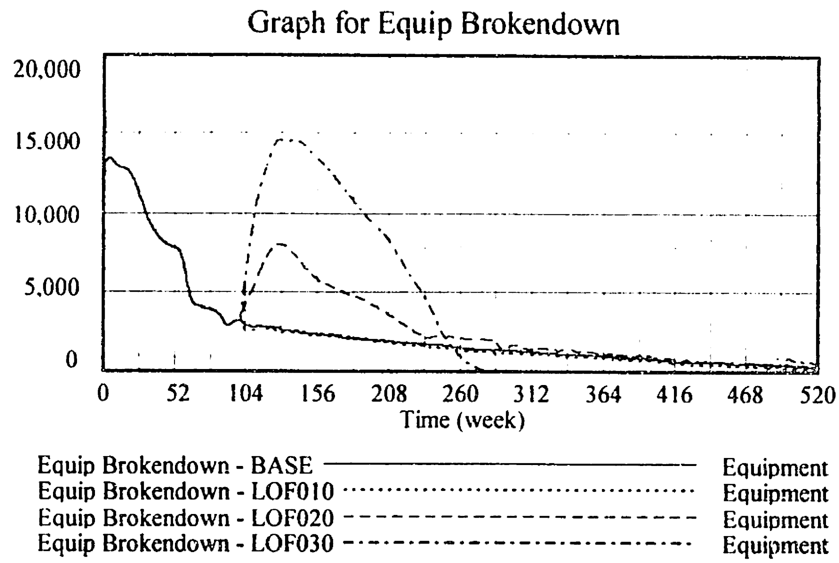


Figure 3.18 Graph for Equipment broken down with D layoff fraction

3.3.10 D target weeks work

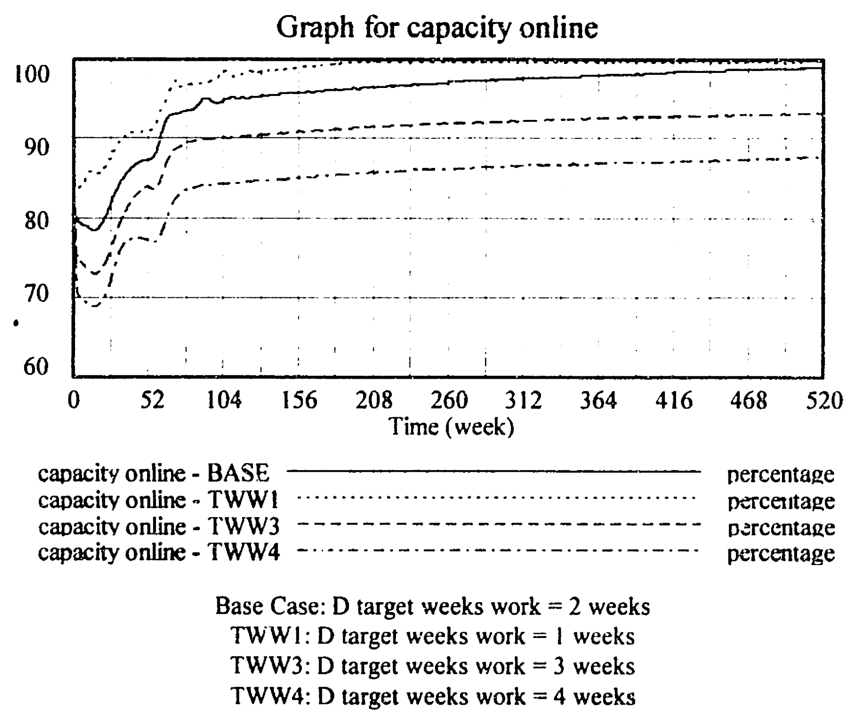


Figure 3.19 Graph for Capacity on-line with D target weeks work

The variable, *D target weeks work*, represents the target backlog, in time, of maintenance work to be maintained. Four different simulations set to 1, 2, 3, and 4 were run. Figure 3.19 shows the effect of varying the target weeks work on capacity on-line. *D target weeks work* determines the workload of maintenance staffs by dividing work to be done in time. If *D target weeks work* decreases, workload increases. As workload increases, it has a positive effect on overtime, and overall productivity of the maintenance workers on work order is getting better. As productivity of workers increases, it has a great positive effect on capacity. If capacity increases, production pressure according to plant demand goes down. This again reduces overtime hours of the maintenance workers. Figure 3.20 shows the effect of varying the target weeks work on workers' productivity, *human effs on WO comp*.

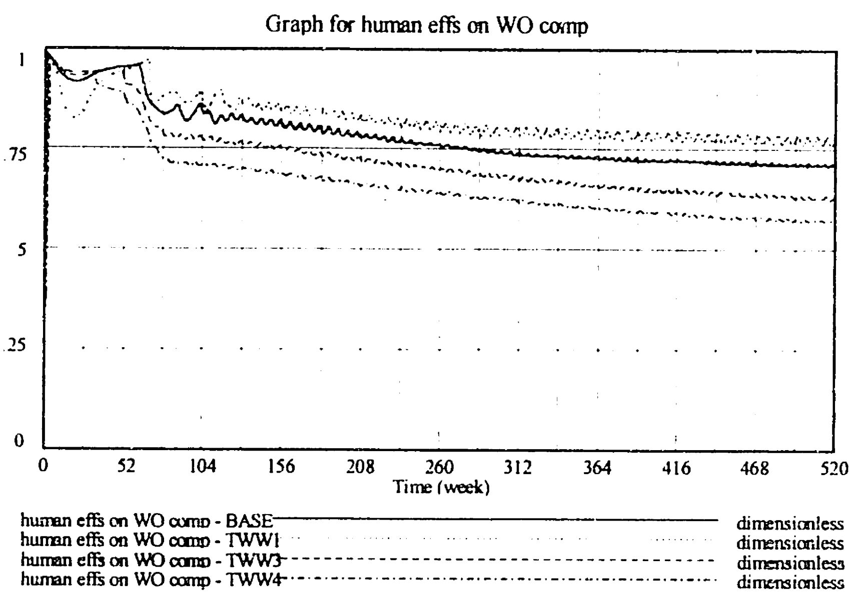
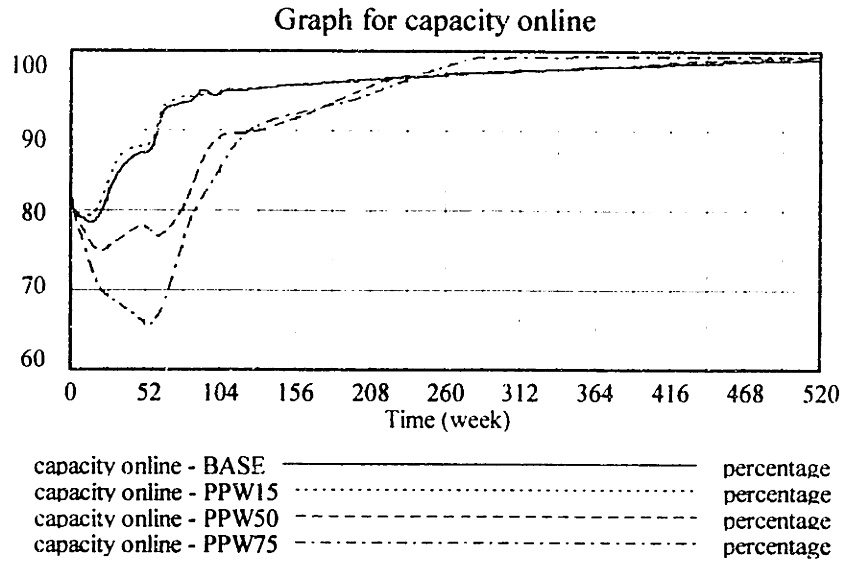


Figure 3.20 Graph for Human effs on WO comp with D target weeks work



Base Case: DR planners per WO mat req = 2.5/40 people /work order
PPW15: DR planners per WO mat req = 1.5/40 people /work order
PPW50: DR planners per WO mat req = 5.0/40 people /work order
PPW75: DR planners per WO mat req = 7.5/40 people /work order

Figure 3.21 Graph for Capacity on-line with DR planners per WO mat req

3.3.11 DR planners per WO mat req

The variable, *DR planners per WO mat req*, represents the number of maintenance staffs assigned to planning an unplanned work order requiring materials. Four different simulations set to 1.5/40, 2.5/40, 5.0/40, and 7.5/40 people/ work order were run.

The effect of varying the planners needed to plan a unplanned work order requiring materials on capacity on-line in Figure 3.21. With 5.0/40 and 7.5/40 cases, the plant model shows the policy sensitivity. As *DR planners per WO mat req* increases, more planners are needed to create plans and acquire materials for work orders requiring materials. Since the fraction of maintenance personnel dedicated to planning is fixed in the model, the plant must hire more maintenance personnel. In both 5.0/40 and 7.5/40 cases, there is a lack of planners available to create plans. This is why planners must be focused on material acquisition for work orders requiring materials. This makes the delay in the process of which work orders are completed. Figure 3.22 shows the effect of varying *DR planners per WO mat req* on normal completion rate of scheduled work order.

But, the actual completion rate of work order considered by worker's productivity shows the reverse effect. This reverse effect is caused by too much strong effect of workload factor among the other factors on worker's performance. With 5.0/40 and 7.5/40 cases, as more planners are needed, their workload increases. Increased workload makes the positive effect on worker's performance. These two simulations are performed with the sets of assumptions for model boundary. The effect of varying *DR planners per WO mat req* on completion rate of scheduled work order is shown in Figure 3.23. The completion rate of scheduled work order dii ly controls the number of defects identified.

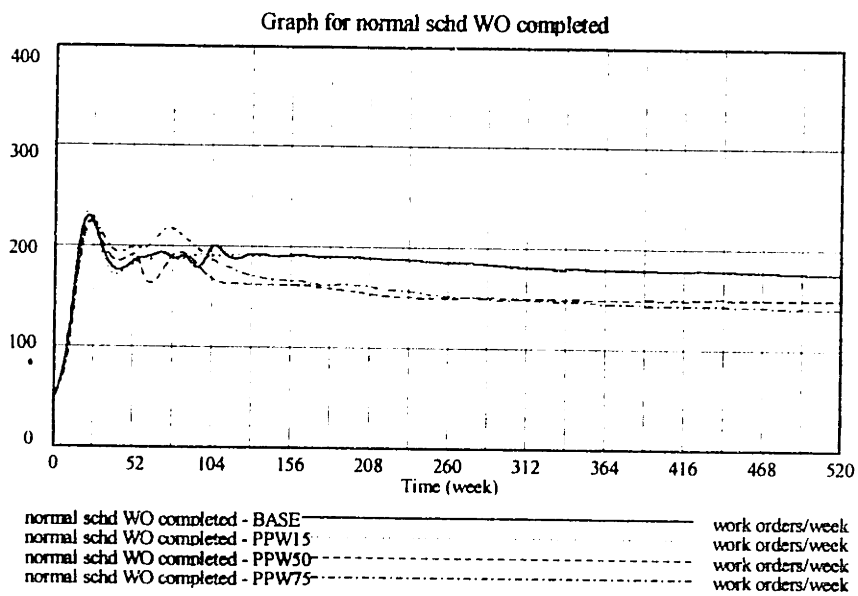


Figure 3.22 Graph for normal schd WO completed with DR planners per WO req mat

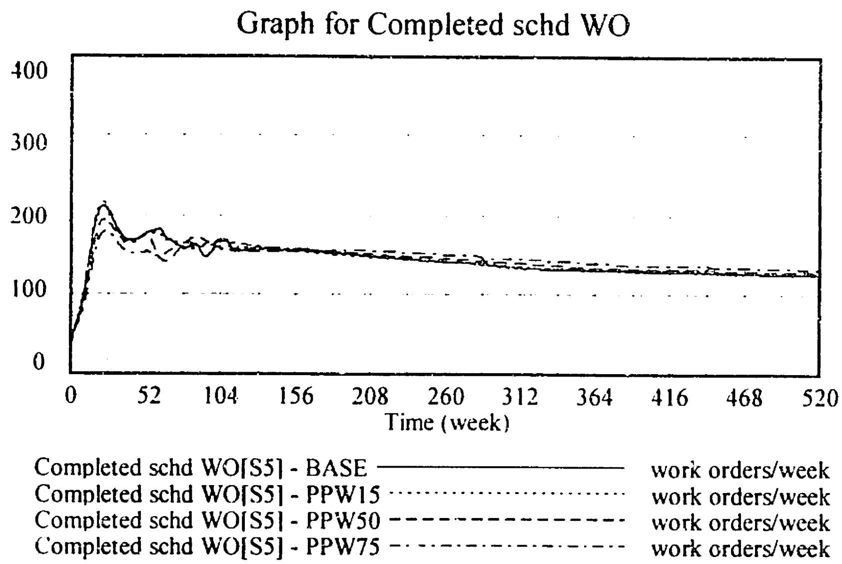
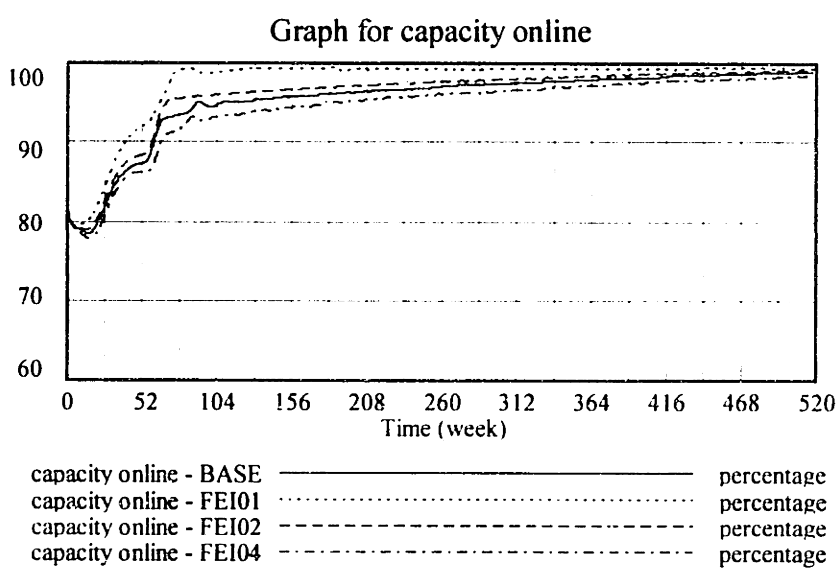


Figure 3.23 Graph for completed schd WO[S5] with DR planners per WO req mat

3.3.12 DR frac eng info

The variable, *DR frac eng info*, is the fraction of engineers allocated to information work. Four different simulations set to 10%, 20%, 30% and 40% were run.



Base Case: DR frac eng info = 0.3
FEI01: DR frac eng info = 0.1
FEI02: DR frac eng info = 0.2
FEI04: DR frac eng info = 0.4

Figure 3.24 Graph for Capacity on-line with DR frac eng info

Figure 3.24 shows the effect of varying the number of information engineers on capacity on-line. As the number of engineers allocated to information increases, more engineers should be taken away from maintenance. The plant does not complete enough maintenance work to maintain capacity. So, capacity on-line goes down. The model can not overcome capacity down by the lack of manpower for maintenance even though more defects can be reduced through information process by increased information engineers. A graph for a multiplier of defect reduction on all defect causes through information process is shown in Figure 3.25. If it is 0.7, defects are reduced by 30%. Eventually, even though reduction in defects causes less on-line breakdowns, much less equipment broken down is repaired due to decreased maintenance work.

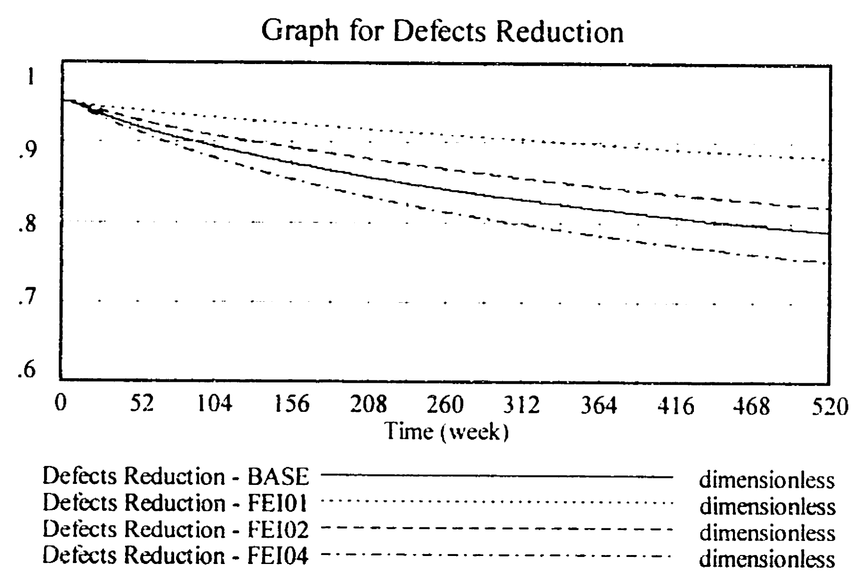
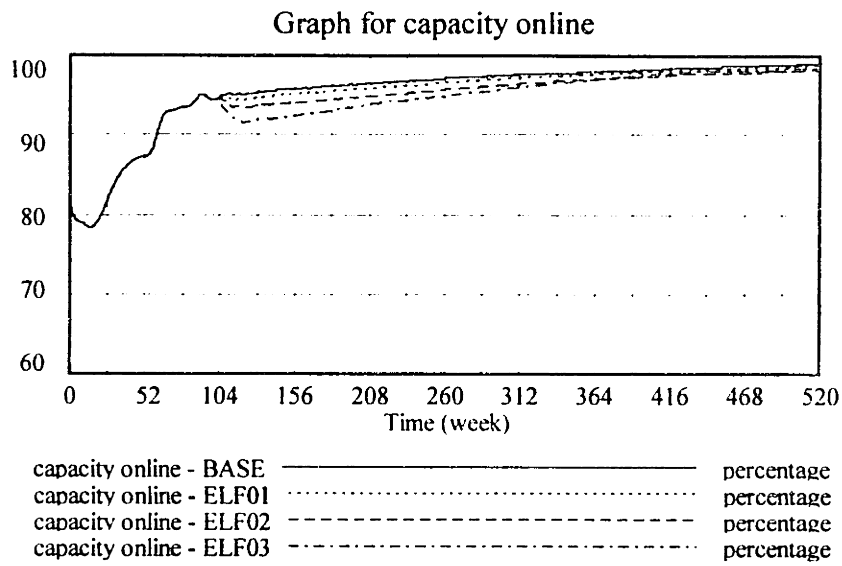


Figure 3.25 Graph for Defect Reduction with DR frac eng info

3.3.13 D eng layoff fraction

The variable, *D eng layoff fraction*, is the fraction of engineer laid off. The fraction of engineer laid off was set to zero until week 100. At 100 week, it was then set to 0%, 10%, 20% and 30%.

Figure 3.26 shows the effect of varying the number of engineers laid off on capacity on-line. As more engineers are laid off, overtime and the workload of remaining engineers increases. After layoffs, average overtime of remained engineers is shown in Figure 3.27. The plant intends to increase capacity through hiring new engineers because too much overtime and workload finally causes lower worker's productivity. As hiring new engineers increases, capacity on-line gradually goes up.



Base Case: D eng layoff fraction = 0%
ELF01: D eng layoff fraction = 10%
ELF02: D eng layoff fraction = 20%
ELF03: D eng layoff fraction = 30%

Figure 3.26 Graph for Capacity on-line with D eng layoff fraction

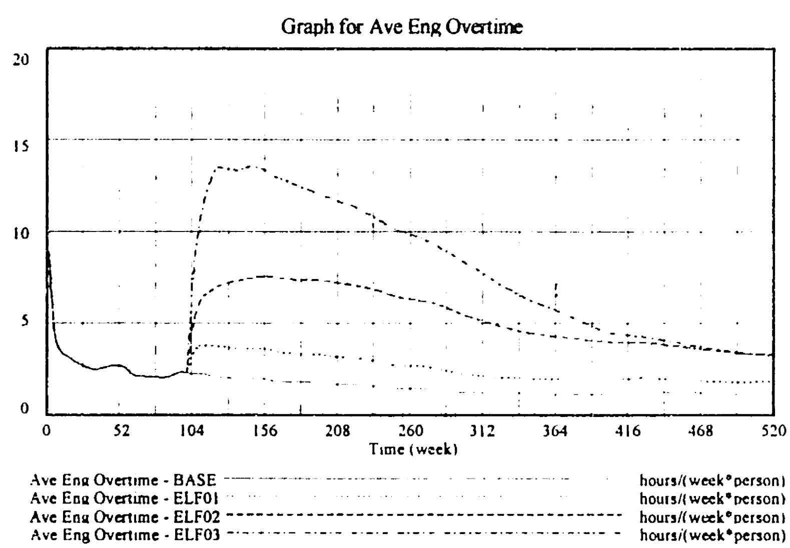


Figure 3.27 Graph for Average Overtime with D eng layoff fraction

3.3.14 DR maint rev per eng per week

The variable , *DR maint rev per eng per week*, is the average number of work orders which an engineer allocated to maintenance work can review during a week. Four different simulations set to 4, 6, 8, and 12 review per engineer per week were run. The simulation results are shown in Figure 3.28.

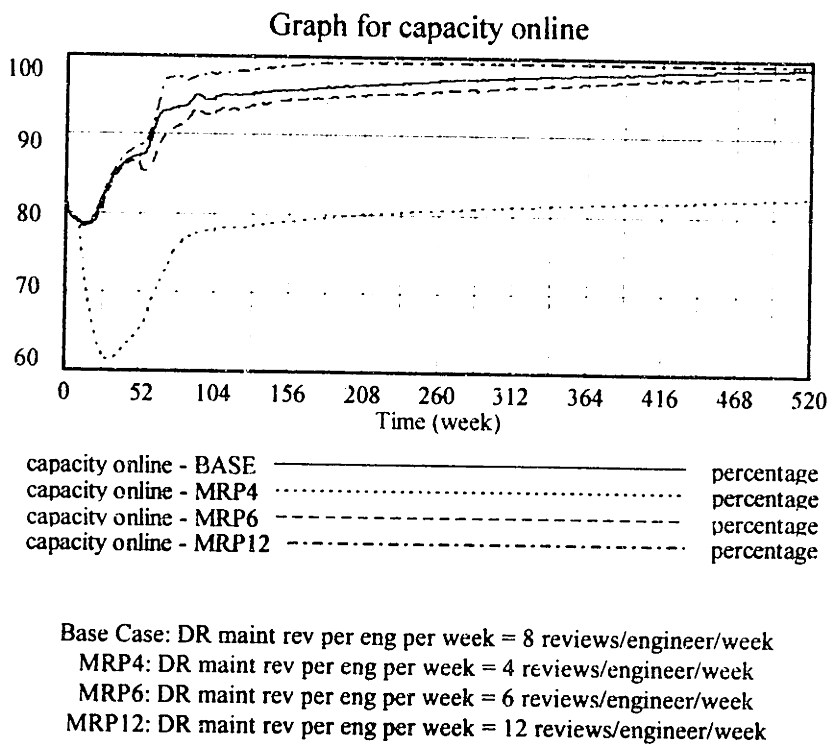
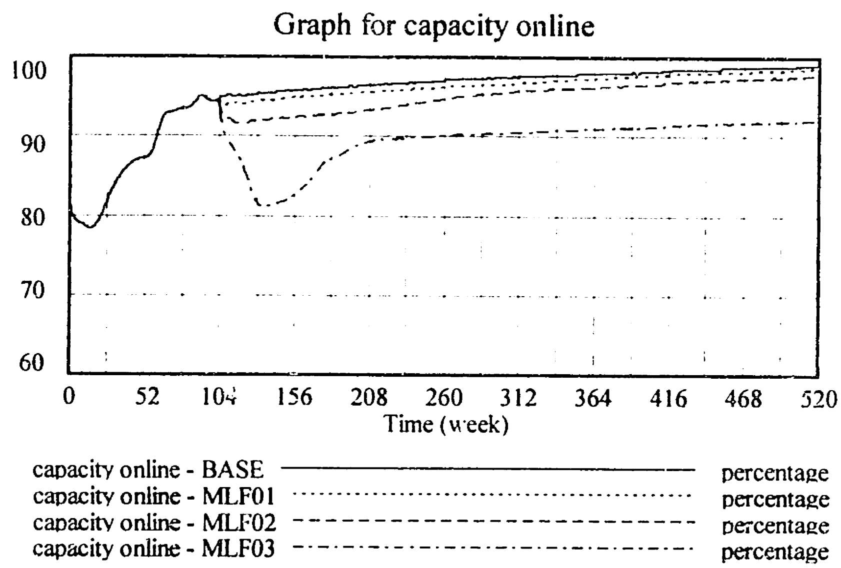


Figure 3.28 Graph for Capacity on-line with DR maint rev per eng per week

This variable determines the flow of work orders moved from the stock of work orders needed to engineer review into the stock of work orders needed to manager review. As *DR maint rev per eng per week* increases, more scheduled and unscheduled work orders are completed for getting rid of defects. If *DR maint rev per eng per week* decreases, workload of engineers allocated to maintenance work increases. The plant must hire more engineers to maintain capacity. With 4 reviews per engineer per week case, there is a big drop in capacity. This is because as the flow of work orders due to delayed engineer's review process is delayed, engineer's workload and fatigue rises up, and this lower seriously engineer's performance. But, the plant model gradually increases capacity by more hiring new engineers.

3.3.15 D mgr layoff fraction

The variable, *D mgr layoff fraction*, is the fraction of managers laid off. The fraction of managers laid off was set to zero until week 100. At 100 week, it was then set to 0%, 10%, 20% and 30%.



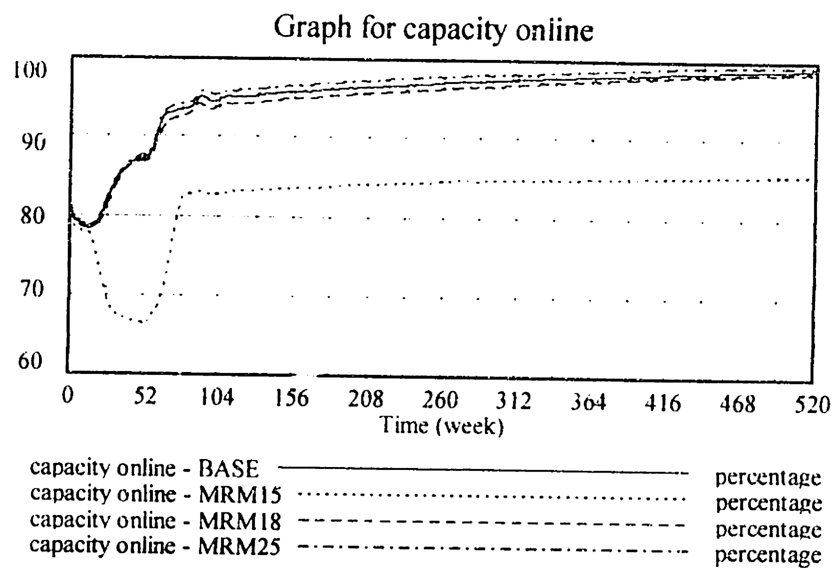
Base Case: D mgr layoff fraction = 0%
MLF01: D mgr layoff fraction = 10%
MLF02: D mgr layoff fraction = 20%
MLF03: D mgr layoff fraction = 30%

Figure 3.29 Graph for Capacity on-line with D mgr layoff fraction

Figure 3.29 shows the effect of varying the number of managers laid off on capacity on-line. As more managers are laid off, overtime and workload of remaining managers increases. Because too much overtime and workload of managers causes fatigue and lower performance, and decreases capacity on-line intends to increase capacity through hiring new managers. With 30% case, there is a big drop in capacity, which is caused by very lower managers' performance from too much workload.

3.3.16 DR maint rev per mgr per week

The variable, *DR maint rev per mgr per week*, is the average number of work order which a manager allocated to maintenance work can review during a week. This determines the flow of work orders from the stock of manager's review to the stock of scheduled work order awaiting equipment. Four different simulations set to 15, 18, 20 and 25 reviews/ manager/week were run.



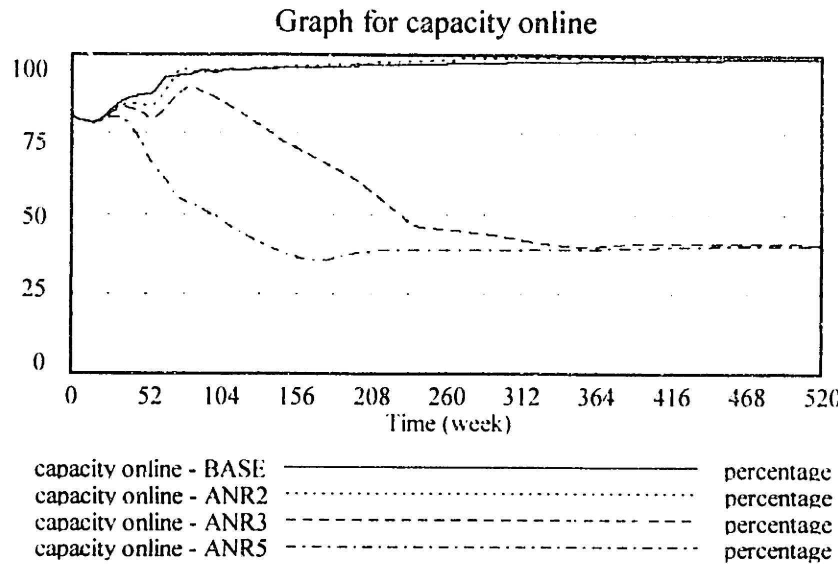
Base Case: DR maint rev per mgr per week = 20 reviews/manager/week
MRM15: DR maint rev per mgr per week = 15 reviews/manager/week
MRM18: DR maint rev per mgr per week = 18 reviews/manager/week
MRM25: DR maint rev per mgr per week = 25 reviews/manager/week

Figure 3.30 Graph for Capacity on-line with DR maint rev per mgr per week

Figure 3.30 shows the effect of varying the average number of work order to be reviewed by a manager during a week on capacity on-line. As *DR maint rev per mgr per week* increases, more scheduled and unscheduled work orders are completed. This removes more defects. If *DR maint rev per mgr per week* decreases, workload of managers allocated to maintenance work like engineer case increases. The plant must hire more managers to maintain capacity. With 25 reviews per manager per week case, there is a big drop in capacity. This is caused by the same mechanism as the one of engineer case mentioned in section 3.3.14.

3.3.17 DR ave no reports per res proj

The variable, *DR ave no reports per res proj*, represents the average number of NRC reports per research project. Four different simulation set to 1, 2, 3 and 5 reports/project were performed.



Base Case: DR ave no reports per res proj = 1 reports/project
ANR2: DR ave no reports per res proj = 2 reports/project
ANR3: DR ave no reports per res proj = 3 reports/project
ANR5: DR ave no reports per res proj = 5 reports/project

Figure 3.31 Graph for Capacity on-line with DR ave no reports per res proj

Figure 3.31 shows the effect of varying the average number of NRC reports per research project on capacity on-line. The increase of *DR ave no reports per res proj* causes the increase of the number of NRC reports in progress and NRC regulation in development. These two factors directly affects the mandatory and discretionary inspections in the plant. Ultimately, the increase of the average number of NRC reports per research project leads to the increase of inspection.

With 2 reports/project case, defects effectively are removed through increased inspections. There is a small drop in capacity due to the increase of equipment taken down for inspections, but capacity gradually increases through reduction in defects.

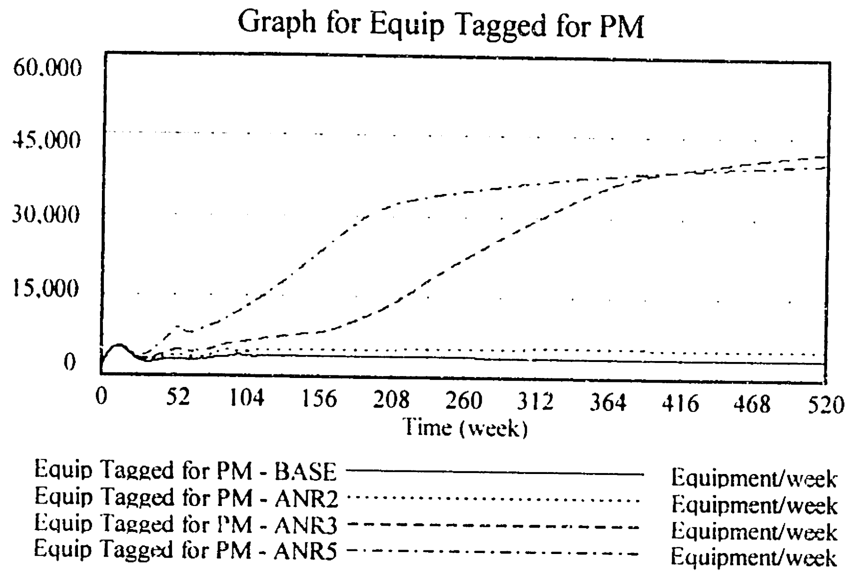


Figure 3.32 Graph for Equipment taken down with DR ave no reports per res proj

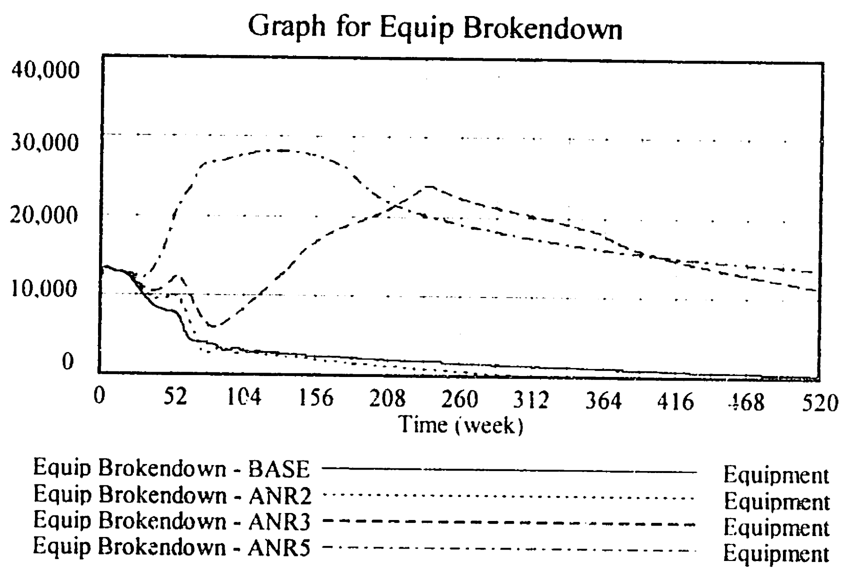


Figure 3.33 Graph for Equipment broken down with DR ave no reports per res proj

With 3 or 5 report/project case, there exists a policy sensitivity. Two assumptions causes too much of increase of inspections. Because the labor budget which is spent on discretionary inspection is fixed in the model, the number of mechanics for discretionary inspections is limited. This leads to a lack of manpower for inspections. Ultimately, a number of pieces of equipment is taken down. Figure 3.32 shows the stock of equipment taken down and Figure 3.33 shows the stock of equipment broken down. The increase of number of pieces of equipment broken down is caused by the decrease of repair rate in spite of decrease in on-line breakdown. This is because the plant must allocate more mechanics into inspection work than other maintenance work. The following graphs show the number of on-line breakdown and the completion rate of unscheduled maintenance work.

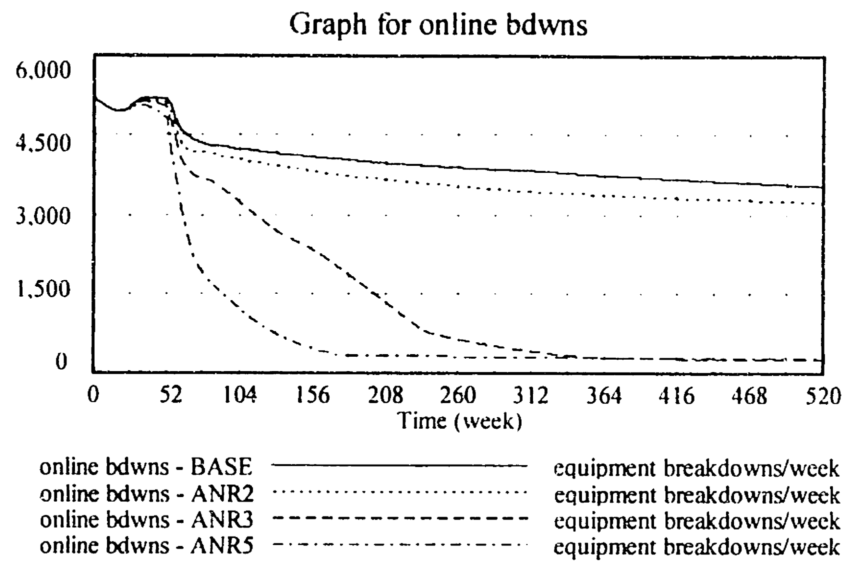


Figure 3.34 Graph for On-line breakdown with DR ave no reports per res proj

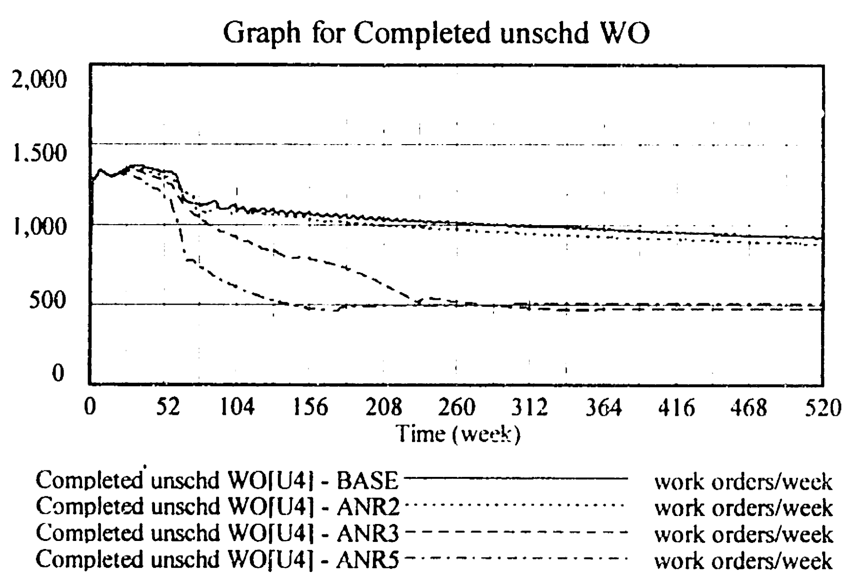


Figure 3.35 Graph for Unscheduled work order completed with DR ave no reports per res proj

3.3.18 DR ave regulations sought per report

The variable, *DR ave regulations sought per report*, represents the average number of regulations sought per report. Four different simulation set to 0.05, 0.1, 0.2 and 0.3 regulations/report were run.

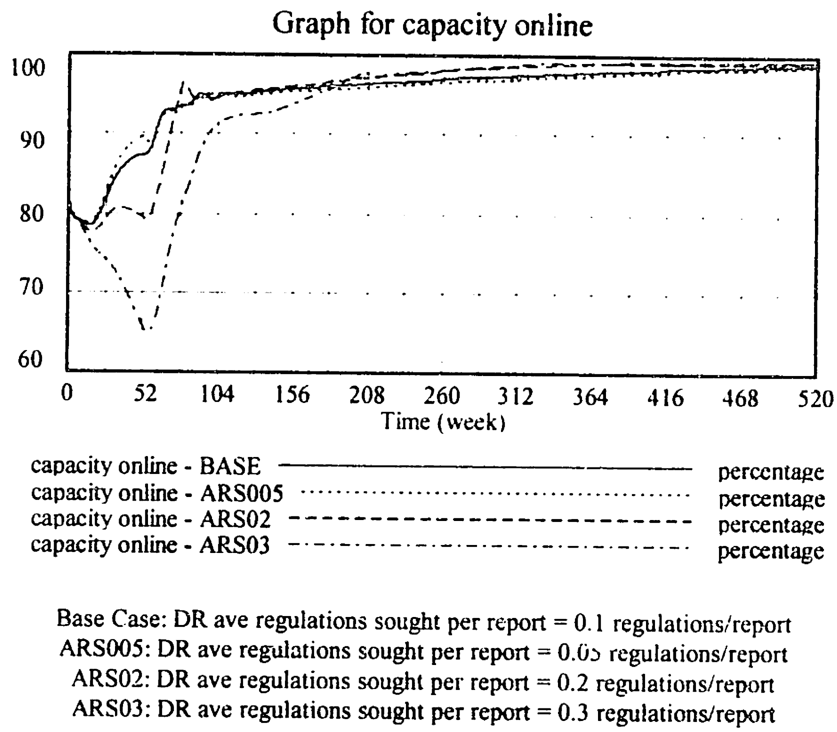


Figure 3.36 Graph for Capacity on-line with DR ave regulations sought per report

Figure 3.36 shows the effect of varying *DR ave regulations sought per report* on capacity on-line. *DR ave regulations sought per report* directly affects both discretionary and mandatory inspections. Increased inspections due to an increase of *DR ave regulations sought per report* reduce defects. But, since inspections abruptly increase, more equipment is needed to be taken down. This causes delayed effect on capacity on-line.

With 0.3 regulations/report case, a big drop is caused by limited number of mechanics for discretionary inspections. Due to fixed budget for discretionary inspections, there is a shortage of manpower for inspections. This makes a jump of equipment taken down.

3.3.19 DR info learning curve fraction

The variable, *DR info learning curve fraction*, is a converter that represents fractional reduction in defect causes for a doubling of corrective actions. Four different simulations set to 0.015, 0.03, 0.04 and 0.05 were performed.

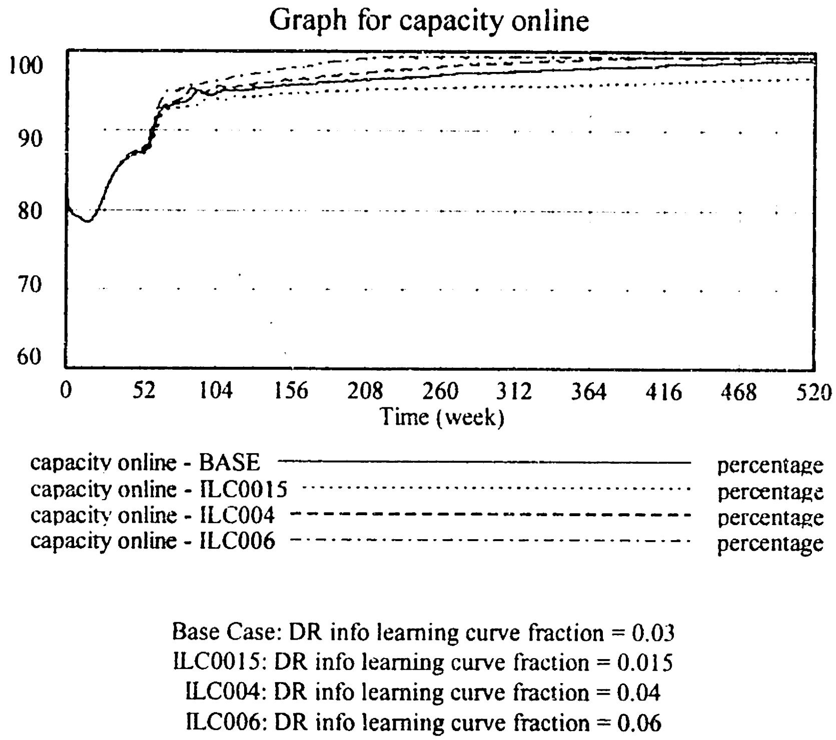


Figure 3.37 Graph for Capacity on-line with DR info learning curve fraction

The larger value of *DR info learning curve fraction*, the more reduction in defect causes. Therefore, as *DR info learning curve fraction* increases, defects decreases. Decreased defects leads to less equipment broken down. Figure 3.37. shows the effect of varying *DR info learning curve fraction* on capacity on-line, and Figure 3.38 shows the effect of varying *DR info learning curve fraction* on defects unidentified.

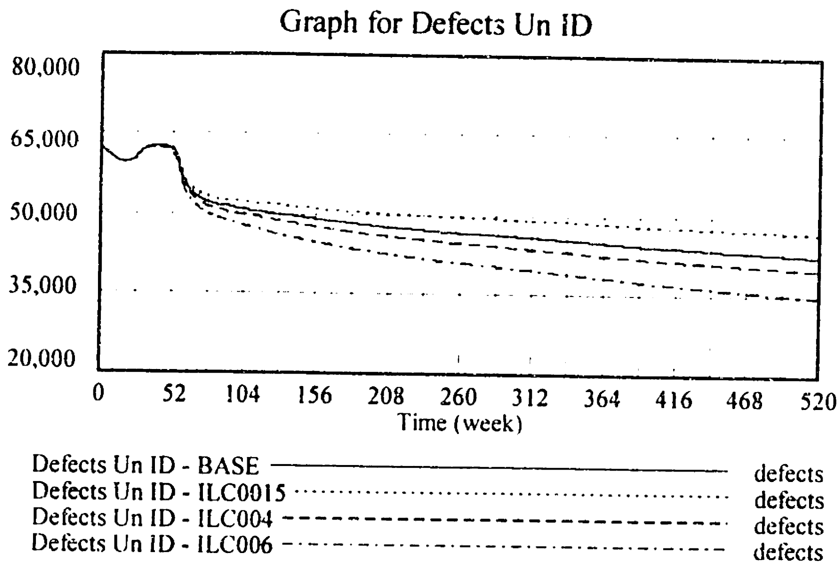
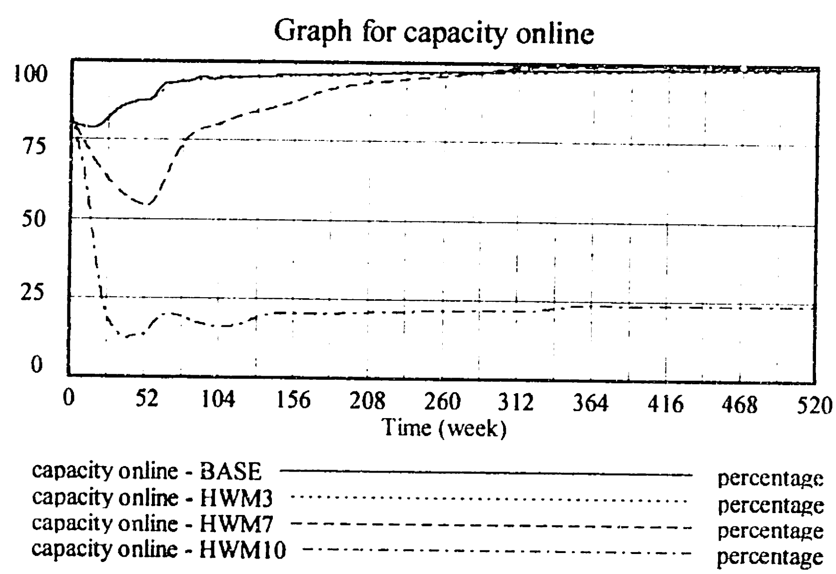


Figure 3.38 Graph for Unidentified defects with DR info learning curve fraction



Base Case: DR HL waste mgt = 5/10E6 million $/ MWe-hr
HWM3: DR HL waste mgt = 3/10E6 million $/ MWe-hr
HWM7: DR HL waste mgt = 7/10E6 million $/ MWe-hr
HWM10: DR HL waste mgt = 10/10E6 million $/ MWe-hr

Figure 3.39 Graph for Capacity on-line with DR HL waste mgt

3.3.20 DR HL waste mgt

The variable, *DR HL waste mgt*, is a converter that represents waste management cost of the plant. Four different simulations set to 3, 5, 7 and 10 $/MWe-hr were run. Figure 3.39 shows the effect of varying *DR HL waste mgt* on capacity on-line.

Waste management cost determines fuel cost. Fuel cost determines operation cost. If waste management cost goes up, fuel cost and operation cost also increases. The initial value of operation cost with initial values of other variables determines *required costs*, which are costs that has little control over in the model. Factors which determines *required costs* are shown as uses tree diagram in Figure 3.40. Finally, when waste management cost increased, required costs also rises up. This directly brings up the effect which lessens the discretionary budget, which is the amount of money the manager can play. The discretionary budget determines the maximum amount of money to be spent on personnel allocation, inspection, and training etc. The discretionary budget, therefore, enormously affects plant performance. Decreased discretionary budget drives to lower capacity. This again affects fuel and operation cost. A graph on fuel cost is shown in Figure 3.41.

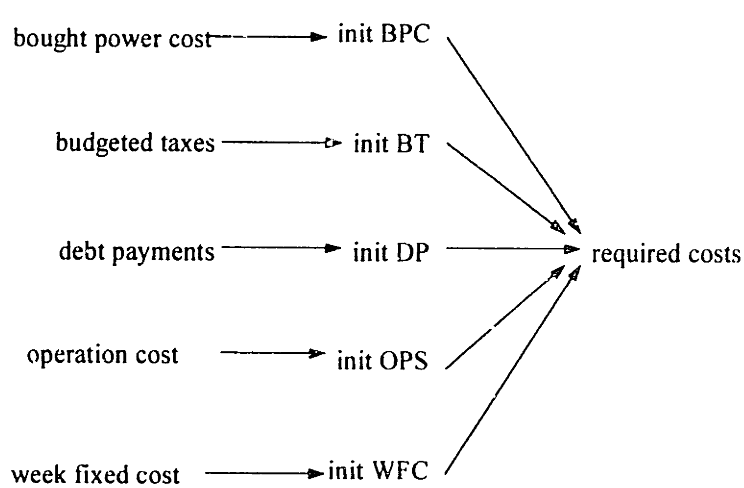


Figure 3.40 Tree Diagram of Required Costs

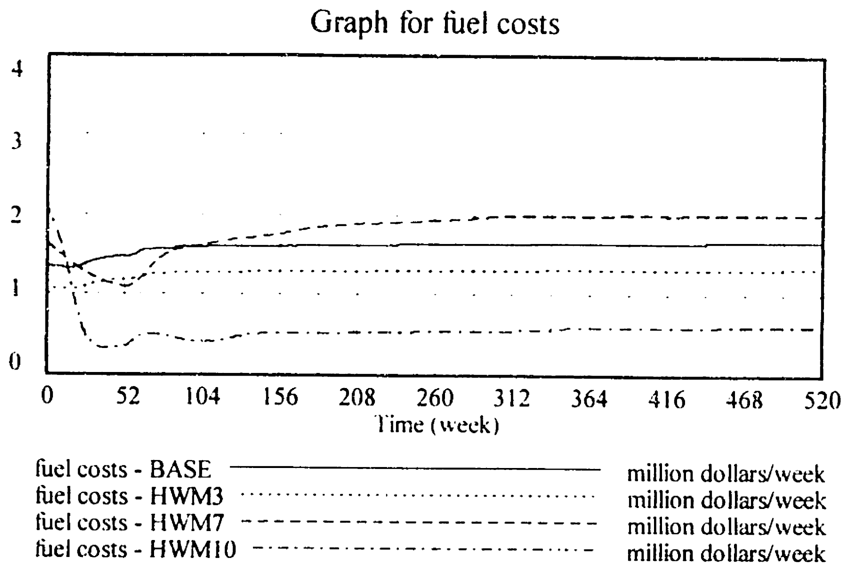
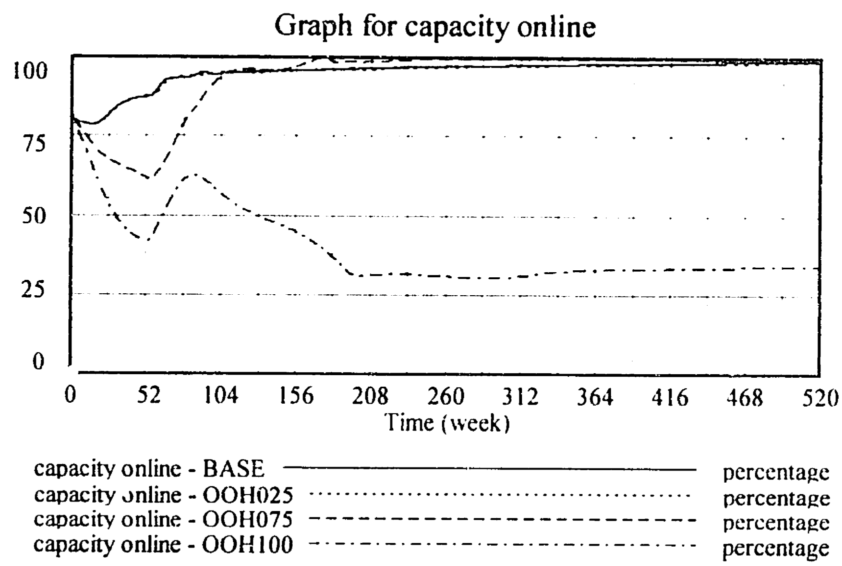


Figure 3.41 Graph for Fuel costs with DR HL waste mgt



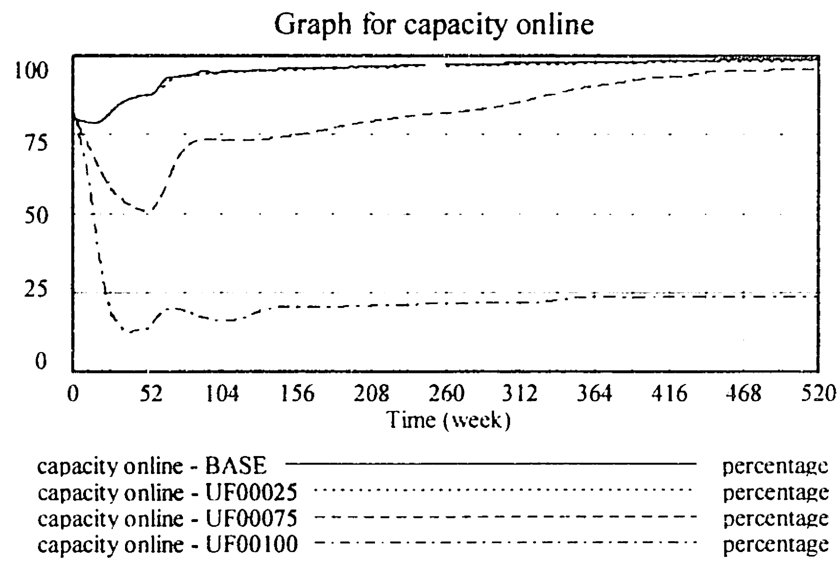
Base Case: DR ops overhead = 0.5 million $/week
OOH025: DR ops overhead = 0.25 million $/week
OOH075: DR ops overhead = 0.75 million $/week
OOH100: DR ops overhead = 1.00 million $/week

Figure 3.42 Graph for Capacity on-line with DR ops overhead

3.3.21 DR ops overhead

The variable, *DR ops overhead*, represents the additional costs incurred in operations such as janitorial services, some paperwork. This variable determines the operation costs. The change of *DR ops overhead* affects the required costs and discretionary budget through the same mechanism as the one of *DR HL waste mgt* mentioned in the preceding section. Figure 3.42 shows the effect of varying *DR ops overhead* on capacity on-line. Figure 3.42 shows an identical pattern of capacity like the graph for capacity with *DR HL waste mgt.*

3.3.22 DR unit $ fuel



Base Case: DR unit $ fuel = (0.005*1000)/10E6 million $/MWe-hr
UF00025: DR unit $ fuel = (0.0025*1000)/10E6 million $/MWe-hr
UF00075: DR unit $ fuel = (0.0075*1000)/10E6 million $/MWe-hr
UF00100: DR unit $ fuel = (0.0100*1000)/10E6 million $/MWe-hr

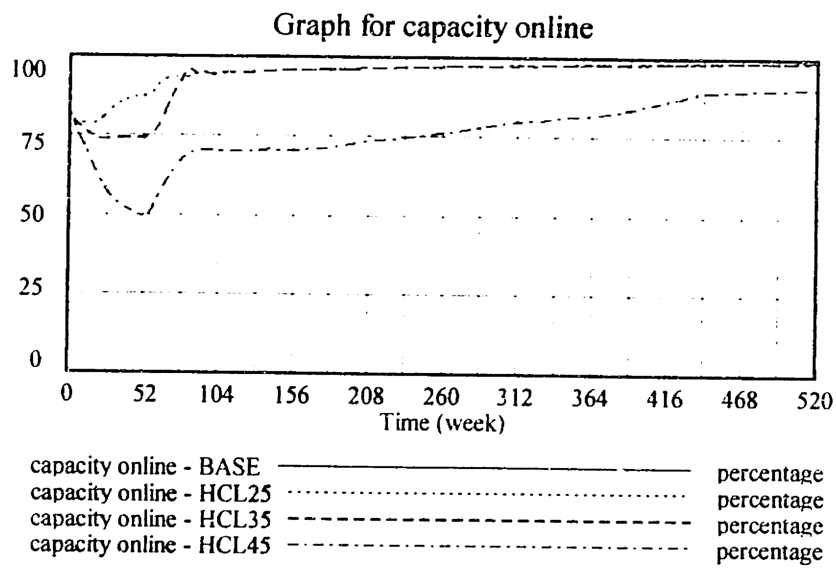
Figure 3.43 Graph for Capacity on-line with DR unit $ fuel

The variable, *DR unit $ fuel*, represents the unit price of fuel required to produce the power of 1 MWe-hr. This variable determines the fuel costs in a week based on capacity. The change of *DR unit $ fuel* also affects operation cost factor and required cost factor through the same mechanism as the one of *DR HL waste mgt* or *DR ops overhead.*

The simulation results shown in Figure 3.43 can be explained identically as the preceding section.

3.3.23 DR hrly cost labor

The variable, *DR hrly cost labor*, is a converter which represents hourly cost of maintenance personnel so as to account for increasing cost of overtime etc. Four different simulations set to 25, 30.59, 35 and 45 dollars per hour were run.



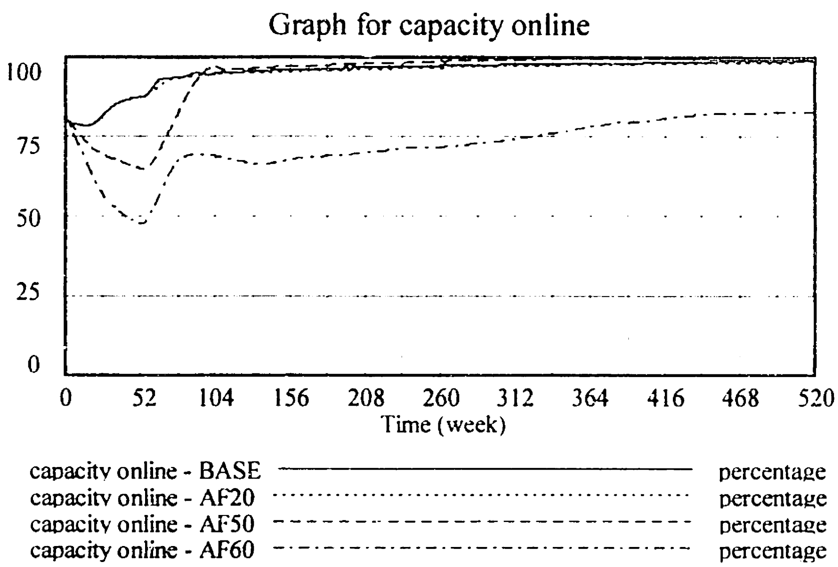
Base Case: DR hrly cost labor = 30.59/10E6 million $/hour
HCL25: DR hrly cost labor = 25/10E6 million $/hour
HCL35: DR hrly cost labor = 35/10E6 million $/hour
HCL45: DR hrly cost labor = 45/10E6 million $/hour

Figure 3.44 Graph for Capacity on-line with DR hrly cost labor

Figure 3.44 shows the effect of varying hourly cost of maintenance personnel on capacity on-line. As hourly cost of maintenance personnel increases, the maximum number of maintenance staff based on budget decreases. The plant can not complete the maintenance work to maintain capacity due to manpower shortage. The big drop in the initial stage is caused by this manpower shortage. The manpower shortage causes an increase of number of pieces of equipment broken down. As equipment broken down increases, NRC pressure the plant into more inspections. The plant removes the defects in the equipment though reinforced inspections and gradually increases capacity.

3.3.24 DR annual fixed costs

The variable, *DR annual fixed costs*, represents the annual costs of maintaining the plant, grounds and bus equipment. It is the same whether or not the plant produces electricity. Four different simulations set to 20, 40, 50, and 60 million dollars per year were run.



Base Case: DR annual fixed costs = 40 million $/year
AF20: DR annual fixed costs = 20 million $/year
AF50: DR annual fixed costs = 50 million $/year
AF60: DR annual fixed costs = 60 million $/year

Figure 3.45 Graph for Capacity on-line with DR annual fixed costs

Figure 3.45 shows the effect of varying *DR annual fixed costs* on capacity on-line. Annual fixed costs positively affects weekly fixed costs. As annual fixed costs increase, the required costs based on the initial value of weekly fixed costs and the initial value of other variables increase. Annual fixed costs affect on discretionary budget through the same mechanism as the one of the variable, *DR HL waste mgt*, etc. Lessen discretionary budget brings up a lack of maintenance manpower. Therefore, during initial transition period there is a big drop in capacity on-line because of increased equipment broken down. This stimulates NRC actions such as reports, regulations, etc. Through NRC actions, the plant is forced to increase mandatory inspections. Finally, more defects are reduced. This leads to a gradual increase of capacity on-line.

Figure 3.46 shows the effect by the change of annual fixed cost on the equipment brokendown and Figure 3.47 shows the effect by the change of annual fixed cost on the total inspection manpower.

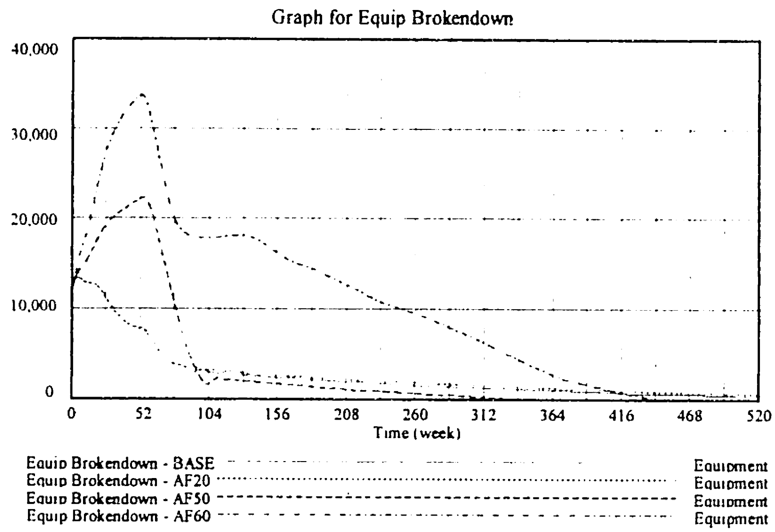


Figure 3.46 Graph for Equipment Broken down with DR annual fixed cost

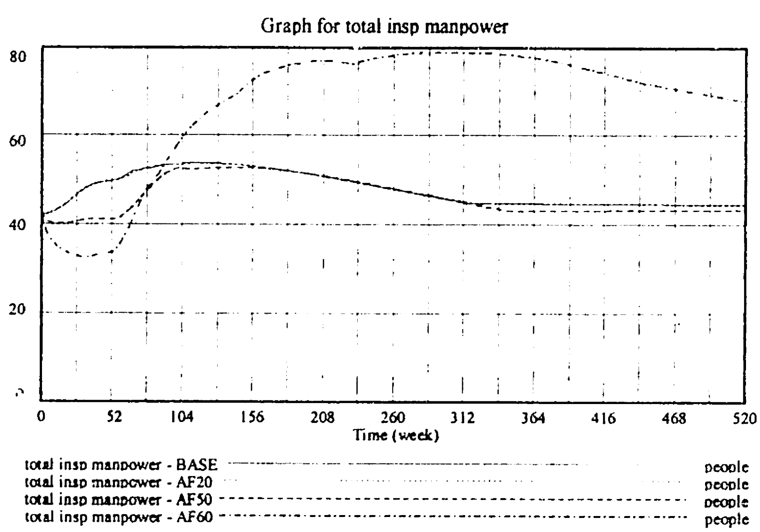
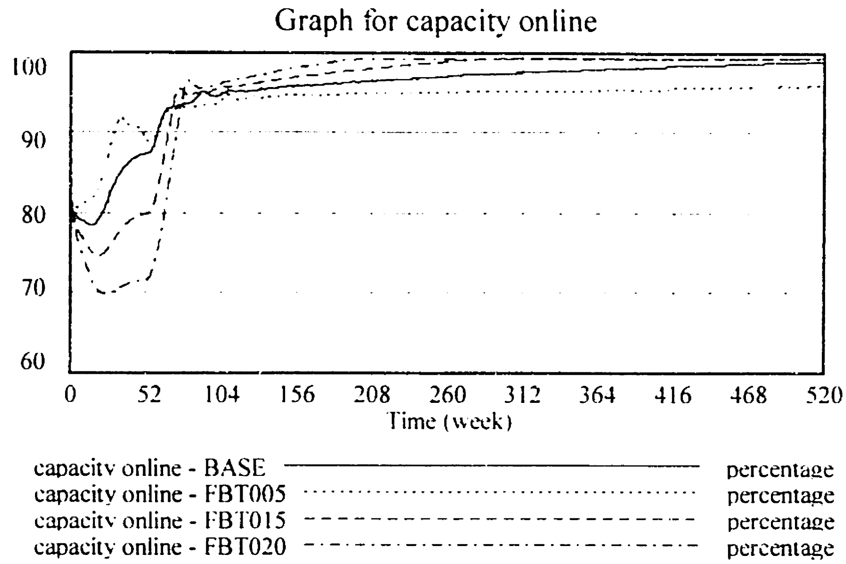


Figure 3.47 Graph for Total inspection manpower with DR annual fixed cost

3.3.25 DR frac bud training

The variable, *DR frac bud training*, represents the portion of the discretionary budget for training. Four different simulations set to 0.05, 0.1, 0.15, and 0.20 were run.



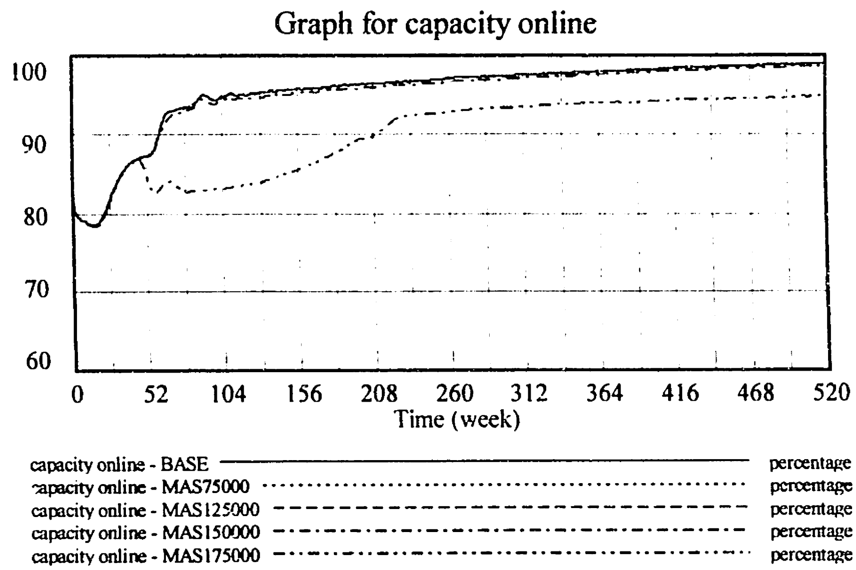
Base Case: DR frac bud training = 0.1
FBT005: DR frac bud training = 0.05
FBT015: DR frac bud training = 0.15
FBT020: DR frac bud training = 0.20

Figure 3.48 Graph for Capacity on-line with DR frac bud training

Figure 3.48 shows the effect of varying the portion of the discretionary budget for training on capacity on-line. An increase of training budget causes an increase of the maximum amount of budget for maintenance staff. As the maximum amount of budget for maintenance staff goes up, the plant can hire more maintenance staffs. On the one hand, this activates the maintenance works and eventually increases the capacity on-line. On the other hand, since there is a shortage of manpower for maintenance work due to training during the initial transition period, a big drop in capacity on-line occurs.

3.3.26 DR mgr annual salary

The variable, *DR mgr annual salary*, represents manager's annual salary. Four different simulations set to 75,000, 100,000, 125,000, 150,000, and 175,000 $/year were run.



Base Case: DR mgr annual salary = 100,000/10E6 million $/year
MAS 75000: DR mgr annual salary = 75,000/10E6 million $/year
MAS125000: DR mgr annual salary = 125,000/10E6 million $/year
MAS150000: DR mgr annual salary = 150,000/10E6 million $/year
MAS175000: DR mgr annual salary = 175,000/10E6 million $/year

Figure 3.49 Graph for Capacity on-line with DR mgr annual salary

Figure 3.49 shows the effect of varying manager's annual salary on capacity on-line. Manager's annual salary determines the maximum number of managers allowed to be hired based on budget. As manager's annual salary increases, the maximum number of managers decreases. The total number of managers determined by varying manager's annual salary is shown in Figure 3. 50. The determined total number of managers directly affect plant performance.

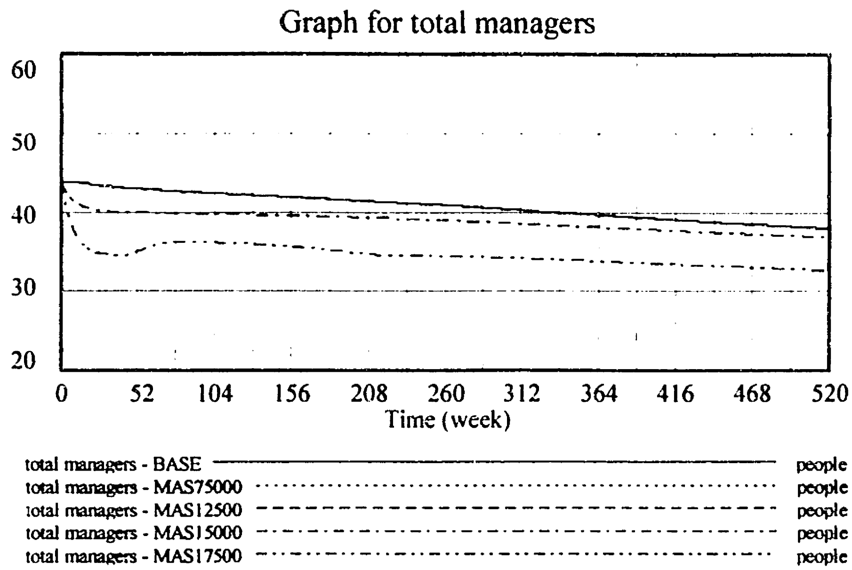


Figure 3.50 Graph for Total managers with DR mgr annual salary

As the total number of managers is reduced, the completion rate of manager's review about scheduled work order decreases. This causes increase in the number of defects identified. Figure 3.51 shows the completion rate of scheduled work order.

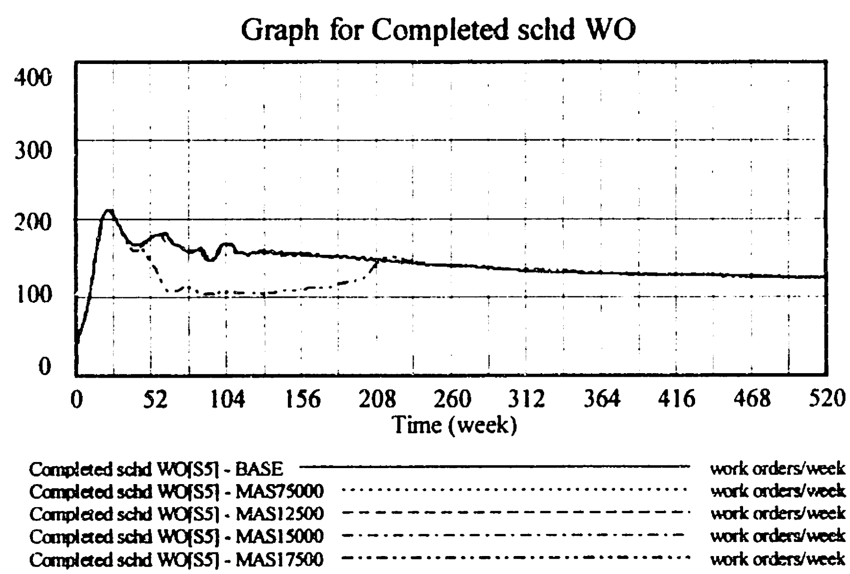


Figure 3.51 Graph for Schd WO comp[S5] with DR mgr annual salary

Consequently, while it is waiting to be inspected or repaired, equipment in the PM system that breaks down increases. The following graph shows the break down rate of the tagged equipment for PM.

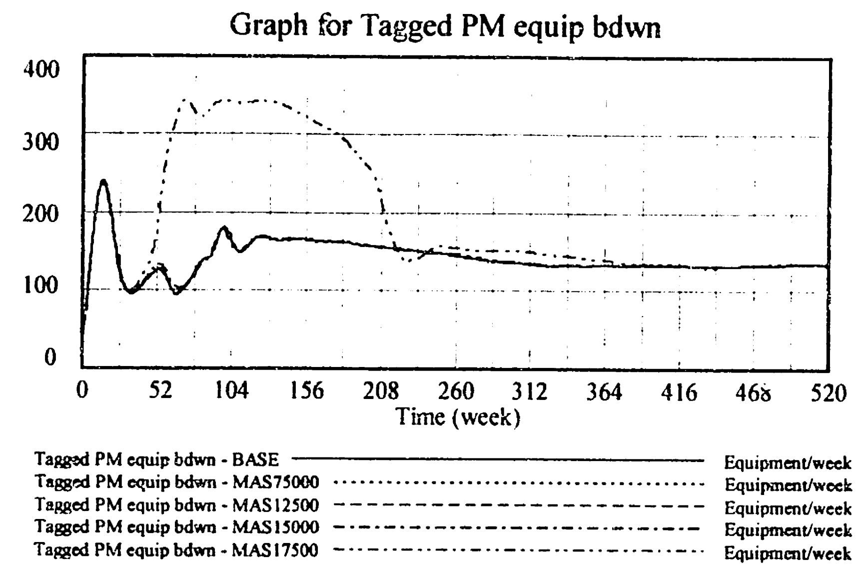
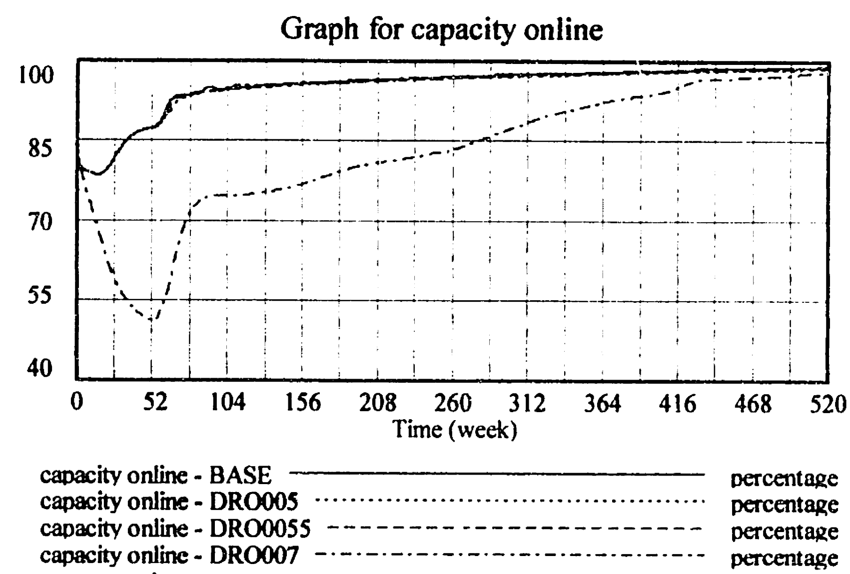


Figure 3.52 Graph for Tagged PM equip bdwn with DR mgr annual salary



Base Case: D desired return on equity = 6%
DRO005: D desired return on equity = 5%
DRO0055: D desired return on equity = 5.5%
DRO007: D desired return on equity = 7%

Figure 3.53 Graph for Capacity on-line with D desired return on equity

3.3.27 D desired return on equity

The variable, *D desired return on equity*, represents the utility's goal for return on equity. Four different simulations set to 5%, 5.5%, 6%, and 7% were run. Figure 3.53 shows the effect of varying *D desired return on equity* on capacity on-line. As the utility's goal for return on equity increases, desired weekly profit increases. This desired weekly profit negatively determines the discretionary budget. Therefore, as the desired return on equity increases, discretionary budget decreases. This is shown in Figure 3.54. Finally, Under decreased budget, the plant is affected by the same mechanism through discretionary budget as mentioned in section 3.3.20.

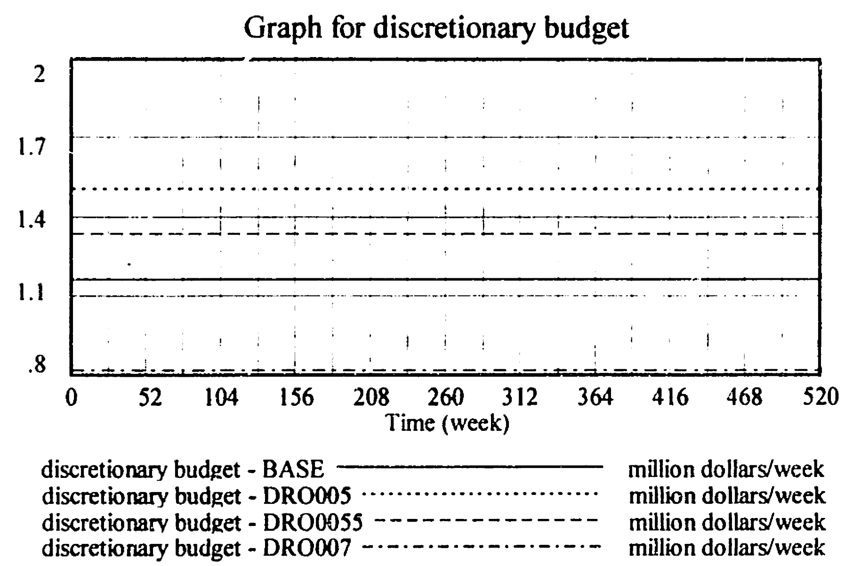


Figure 3.54 Graph for Discretionary budget with D desired return on equity

3.4 Discussions of Sensitivity Studies

So far, we have studied the effect of changes of various parameters including budgeting parameters, materials delay, work approval delay, personnel allocation and layoffs, etc. Comparisons between base case and other cases give insights about structure and behavior of the model. This section discusses identifying the major factors as a mechanism which alters behavior of the model, active parts of the model, uncertainty of the simulation results, and further work in the sensitivity analysis.

3.4.1 Major Mechanisms

As for the changes of parameters, only twenty-six 'key variables' have great impacts on behavior of the model. It was also found that behavior of the model mainly depends on several factors; discretionary budget, productivity, defect causes, manpower, and work to be done. In general, the changes of one key variable directly influence on behavior of the model through one factor above. In other words, the plant performance mainly is determined by these factors in the Nuclear Utility Model.

Discretionary budget is the most important factor in the financial resources of the plant. This is why discretionary budget determines various budget for manager to maintain the plant performance and relative safety. The plant can also control the manpower for maintenance work through discretionary budget. By the discretionary budget, the maximum number of manpower to be hired is determined.

Worker's productivity directly affects the completion rate of work orders. The model assumes that it is affected by three productivity factors such as motivation, fatigue and workload. The model assumes that the motivation factor is fixed, high fatigue according to overtime lower productivity, and high workload raise productivity. Workload is defined as people's desire to make the available work fit the available time. But, as people's desire to make the available work fit the available time increases, the stress of people also increase. So, this reverse effect on productivity should be considered in determining the productivity. Workload positively affects average overtime hours per worker per week. That is, as workload increases, overtime increases. As a result, productivity is determined by balancing between the effect of workload factor and the effect of overtime factor on productivity.

Since various factors are not considered as productivity factors, we can just approximately figure out worker's productivity. Consequently, due to the effect of unreliable productivity we can get an unpredictable results about behavior of the model. For example, with a variable, *DR planners per WO mat req*, case in the section 3.3.11, the actual completion rate of work order considered the worker's productivity bear the different results with normal completion rate of work order not considered it.

The different assumptions of some variables changed the behavior of the model by changing defect causes. The creation rate of defect determines breakdown rate of equipment, which directly affects capacity on-line.

Many parameters simulated are related to a mechanism through the amount of manpower. Manpower determines how fast worker can complete his work. A shortage of manpower causes high workload and overtime work. A shortage of manpower occurs in case that few worker can be hired under limited budget or in case that too many workers are allocated to the other work.

Finally, some parameters change behavior of the model by changing the amount of work to be done. The change of maintenance work to be done which is made by controlling the flows of work orders affects manpower demand for maintenance work or equipment taken down or equipment broken down.

Five main factors affect each other, and besides there can be other factors that affect behavior of the model. But, since these factors have relatively great influences on the behavior of the model, five factors can be considered as dominant factors which affect behavior of the model. Therefore, parameters related to these factors are required to obtain thoroughly precise data in the industry. All key variables can be categorized into factors which they mainly affect. Table 3.2 represents relationship between the main factors and key variables which affect behavior of the model by mechanisms of main factors.

Table 3.2 Main Factors affected by Key Variables

Factors	Key Variables
Discretionary budget factor	DR customer demand DR HL waste mgt DR ops overhead DR unit $ fuel DR hrly cost labor DR annual fixed costs DR frac bud training D desired return on equity
Productivity factor	D layoff fraction D target weeks work DR planners per WO mat req D eng layoff fraction DR maint rev per eng per week D mgr layoff fraction DR maint rev per mgr per week
Defect Causes factor	DR frac dfct bdwn DR base dfcts ops per week DR info learning curve fraction
Manpower factor	DR mech experience cost factor DR frac eng info DR ave no reports per res proj DR ave regulations sought per report DR mgr annual salary
Work to be done factor	DR equip per WO DR mat acq delay DR unschd backlog time

3.4.2 Active Parts of the Model

Through sensitivity analysis, the active and dominant parts of this utility model were identified. The most important parts which have great impacts on plant performance includes the internal area of the utility such as the nuclear power plant sector and the financial resources sector. The key variables from these sectors changes capacity on-line with large amplitude and different pattern of behavior of the model. However, parameters from the social sector almost does not affect capacity on-line. In the government sector parameters which control the NRC regulation system produce a great effect on plant performance. Parameters included in the information sector only have indirect impacts upon plant performance

In conclusion, the validity of all parameters in the active parts of the model must be thoroughly investigated before simulating the model. This is why simulation results are sensitive to values of these parameters. Effort should be put into estimating or reformulating these parameters, while the other parameters are left at their low level of precision, which still is sufficient to let the model fulfill its purpose.

3.4.3 Uncertainty of Simulation Results

So far we have discussed various mechanisms which change behavior of the model. The discussions in section 3.3 show that the important variables behave reasonably as expected based on the different assumptions. But it was found that simulation results can be changed depending on the various assumptions introduced. The simulation results depend on both the magnitudes and the rates of changes of parameters. Therefore, the process of verifying whether or not the simulated results are consistent with the data in the industry is required.

Furthermore, there is no fixed measure for analysis of simulation results. In this thesis, we have only considered relative changes of pattern of plant performance over the time as for sensitivity analysis. It can provide us which variables are relatively important. However, it can not give us how much sensitive the variables are. A specific indicator which tell the absolute degree of sensitivity of the variables to simulation results is required in the sensitivity analysis.

3.4.4 Further Work on Sensitivity Analysis

As mentioned before, for the purpose of this thesis, only parameter not including initial value of the stock were simulated for sensitivity analysis. Broadly speaking, sensitivity can extend beyond parameters. First, we must examine the initial value of the stock variables, other model equations, and table function graphs such as lookup functions through identical process introduced. We must not only consider sensitivity to numerical assumptions such as parameter values, but also sensitivity to assumptions about the model boundary.

Chapter 4

4.1 Summary and Conclusions

The Nuclear Utility Model has been developed for policy makers who need to use it as a tool to make accurate managerial decisions. Before the model is used as a reliable tool, its structure should be analyzed to verify whether patterns of behavior of the model truly depict behavior of a certain utility or not. Also validation of the model variables whose values have uncertainty is required to be investigated prior to obtaining the precise data from the utility. Sensitivity analysis is used as an analytical tool for understanding the model's structure and identifying the key variables of the model. The key variables are the variables that have the potential to alter the model's behavior mode.

In this sensitivity study, only 221 parameters which are not including initial values of the stock variables were changed. To find key parameters, each parameter has been simulated three or four times respectively with the different assumptions. The changes of the values of each parameter were made with plausible enough alternative assumptions to be analyzed. To accomplish the sensitivity analysis, the effect on capacity on-line of varying parameter's values was considered. This is why capacity on-line is the most important indicator of performance and relative safety of the utility.

As the results of sensitivity analysis, only 26 parameters among the total 221 parameters were categorized into the key variables which have great impact on the behavior of the model. Several mechanisms which primarily govern the relation between parameter's change and change of the behavior of the model were revealed through understanding change of the behavior mode of the model due to key parameter's change.

The major mechanisms can be summarized as follows:

- Discretionary budget determines various budget for manager to maintain the plant performance and relative safety, and the maximum hiring rate of manpower for maintenance work through the budget determined.
- Worker's ·productivity directly affects the completion rate of work orders for maintenance work.
- The change of defect causes affects the creation rate of defects which determines the break-down rate of equipment.
- The amount of manpower controls the relation between workload and overtime.
- The change of maintenance work to be done, which is made by controlling the flows of work orders, affects manpower demand for maintenance work or equipment taken down or equipment broken down.

The dominant and active parts of the model were identified as the internal area of the utility model including the nuclear power plant and financial resources sector. All parameters in these active parts must be thoroughly investigated and reformulated before simulating the model for accurate simulation results.

Further work is needed on the utility model before it can be used as an effective tool for policy makers. The mechanism of worker's productivity importantly affects the plant performance. However, the current utility model is not real in the worker's productivity. Refinement of this productivity factor is required to depict real-life. Sensitivity analysis should also extend to initial values of the stock variables and assumptions about the model boundary beyond parameters for validation of the model.

In conclusion, sensitivity analysis is a useful method for model builders and managers to understand the behavior and structure of the model, and the real-world system. It also allows them to determine the variables needed to get more precise data from the industry by determining the key model variables which have great impact on the simulation results.

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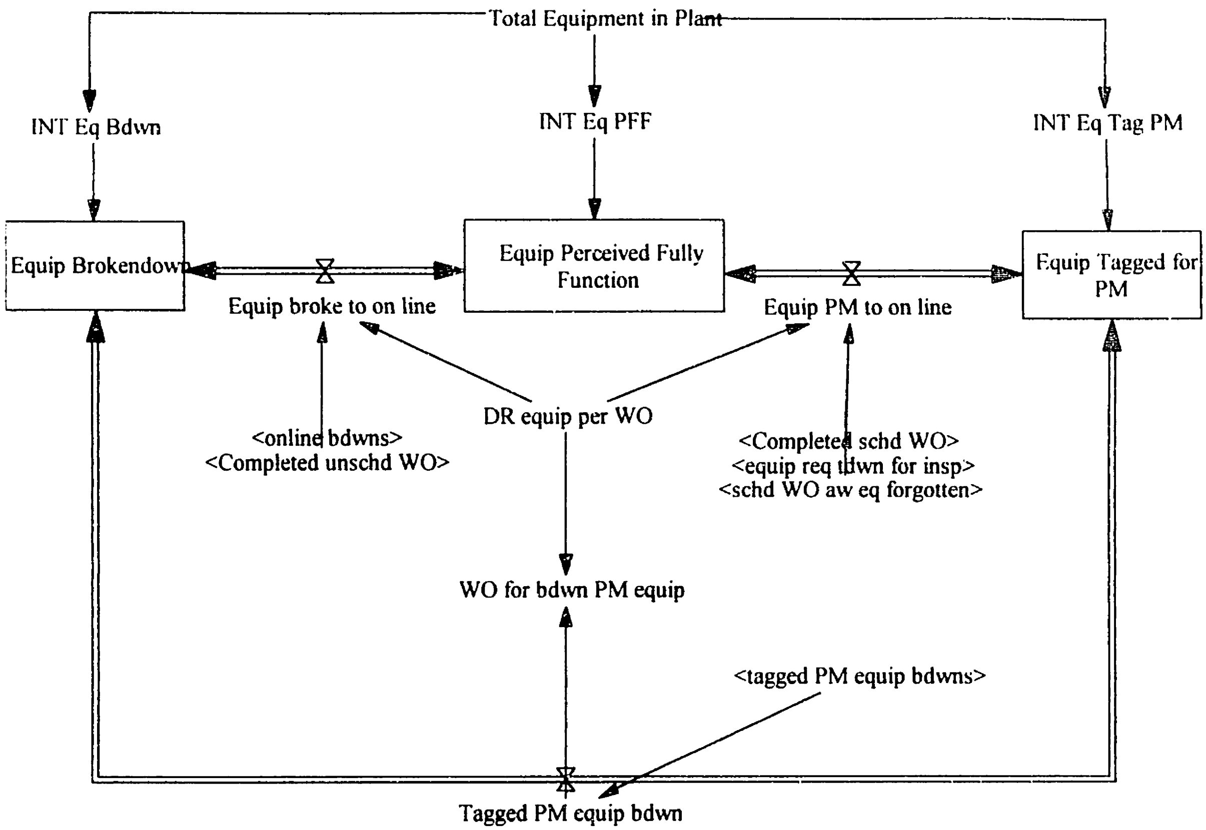
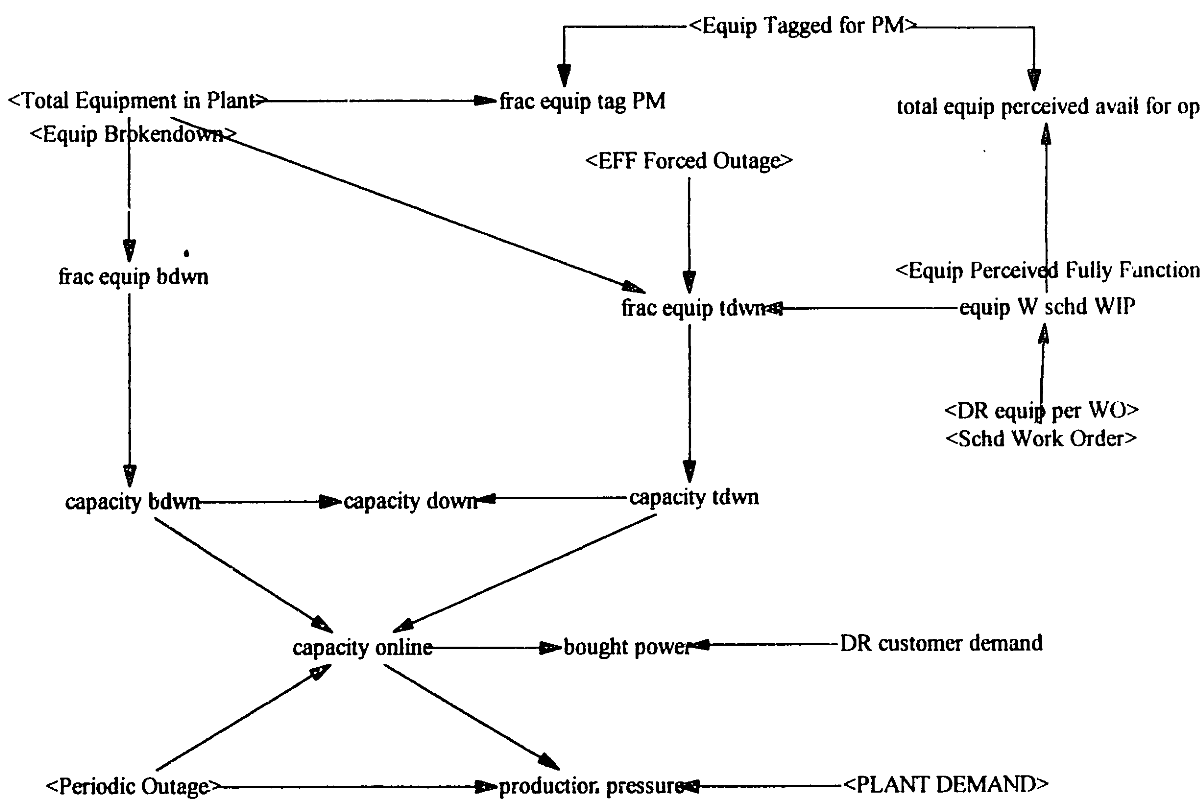
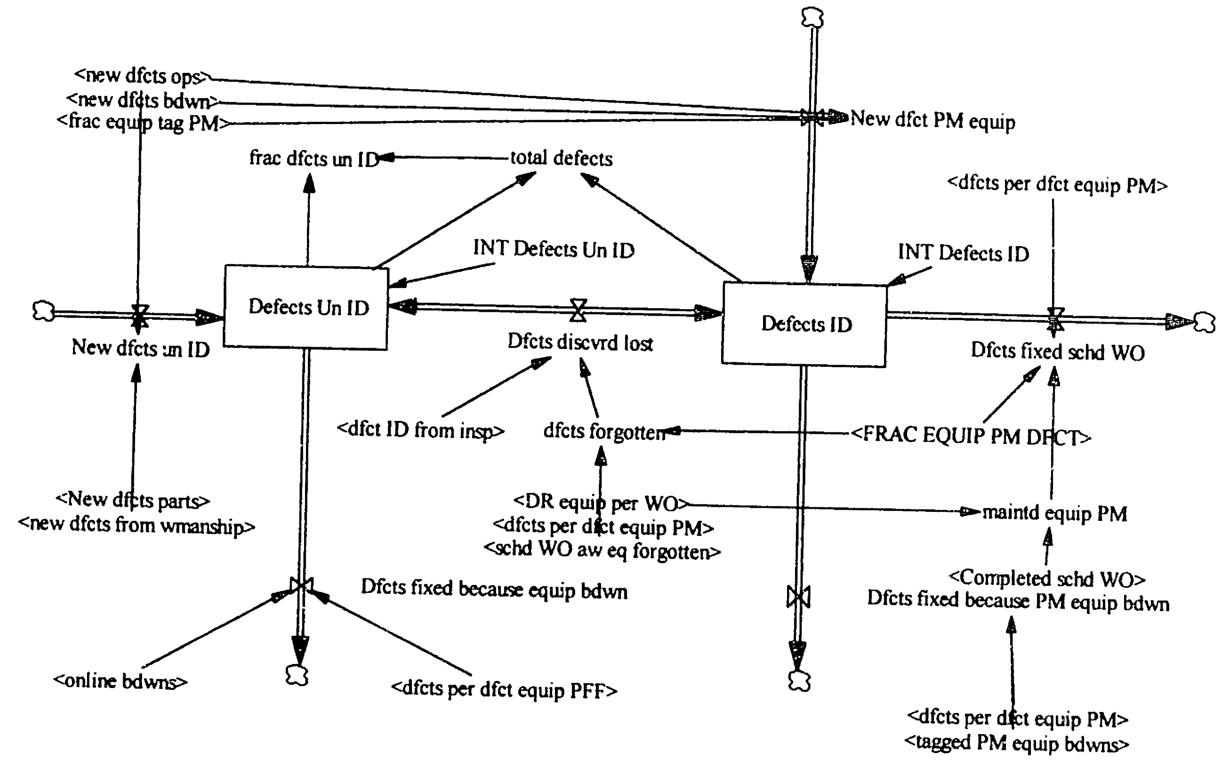
Appendix A: Stock-Flow Diagram of the Nuclear Utility Model



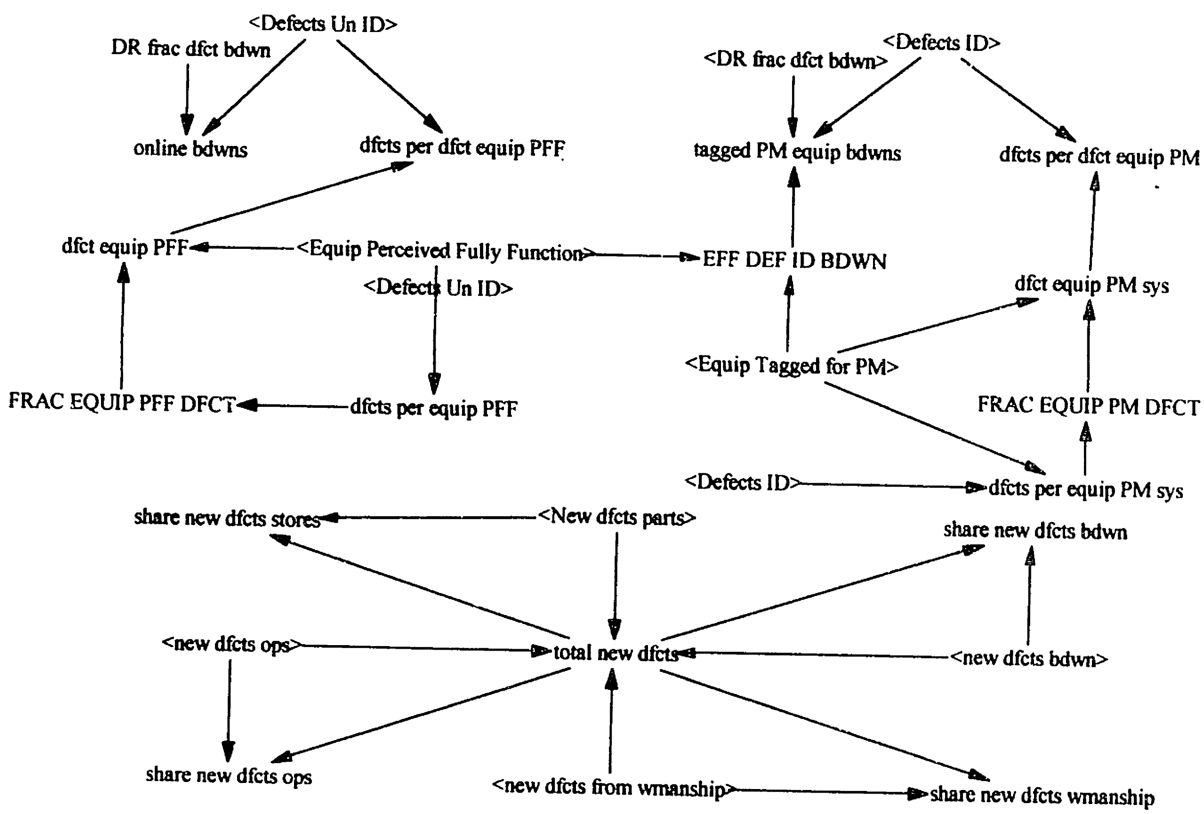
View 1: Equipment Flows



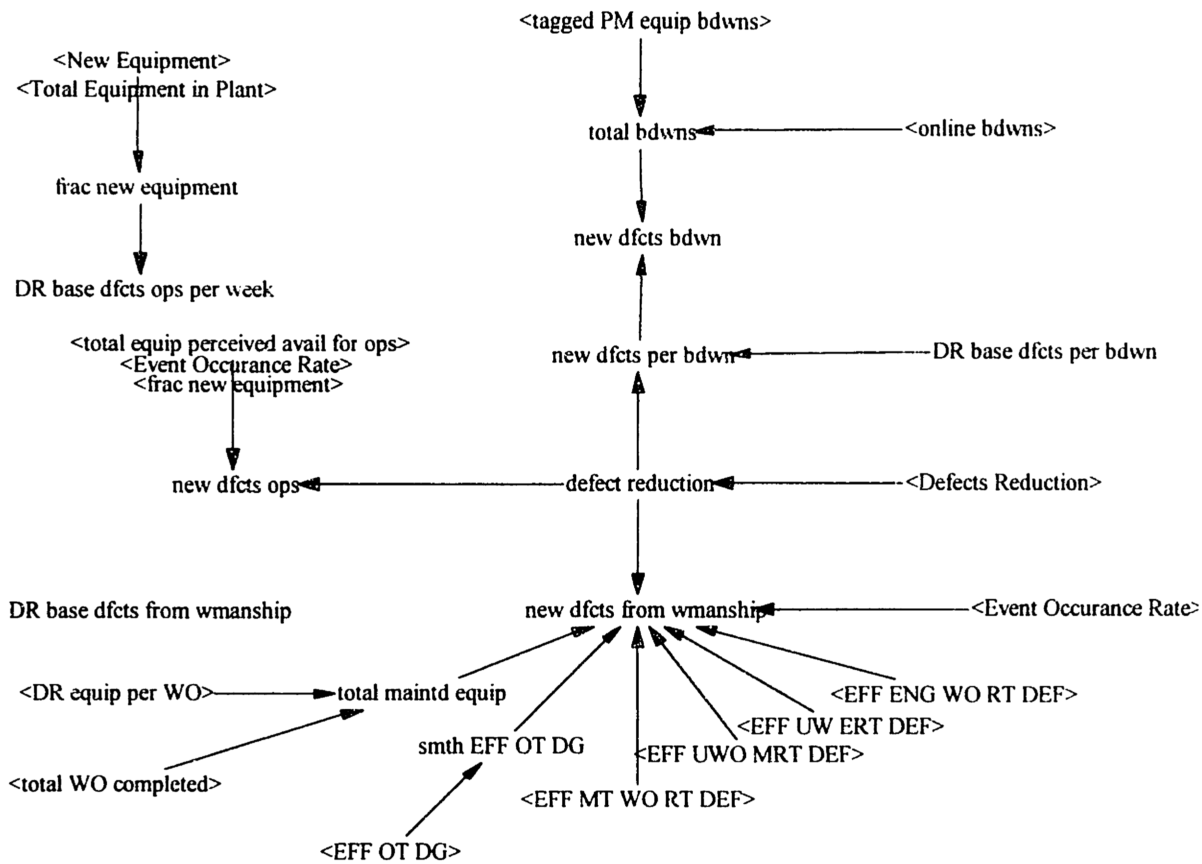
View 2: Capacity Calculation



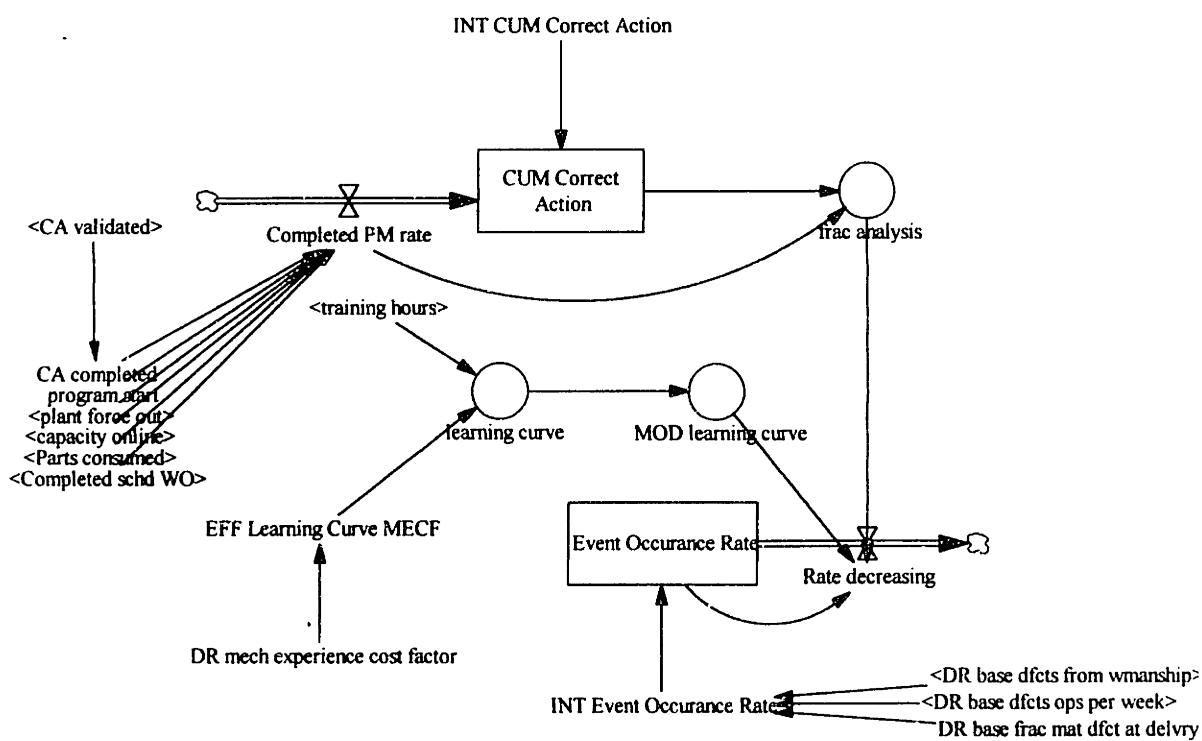
View 3: Defect Flow 1



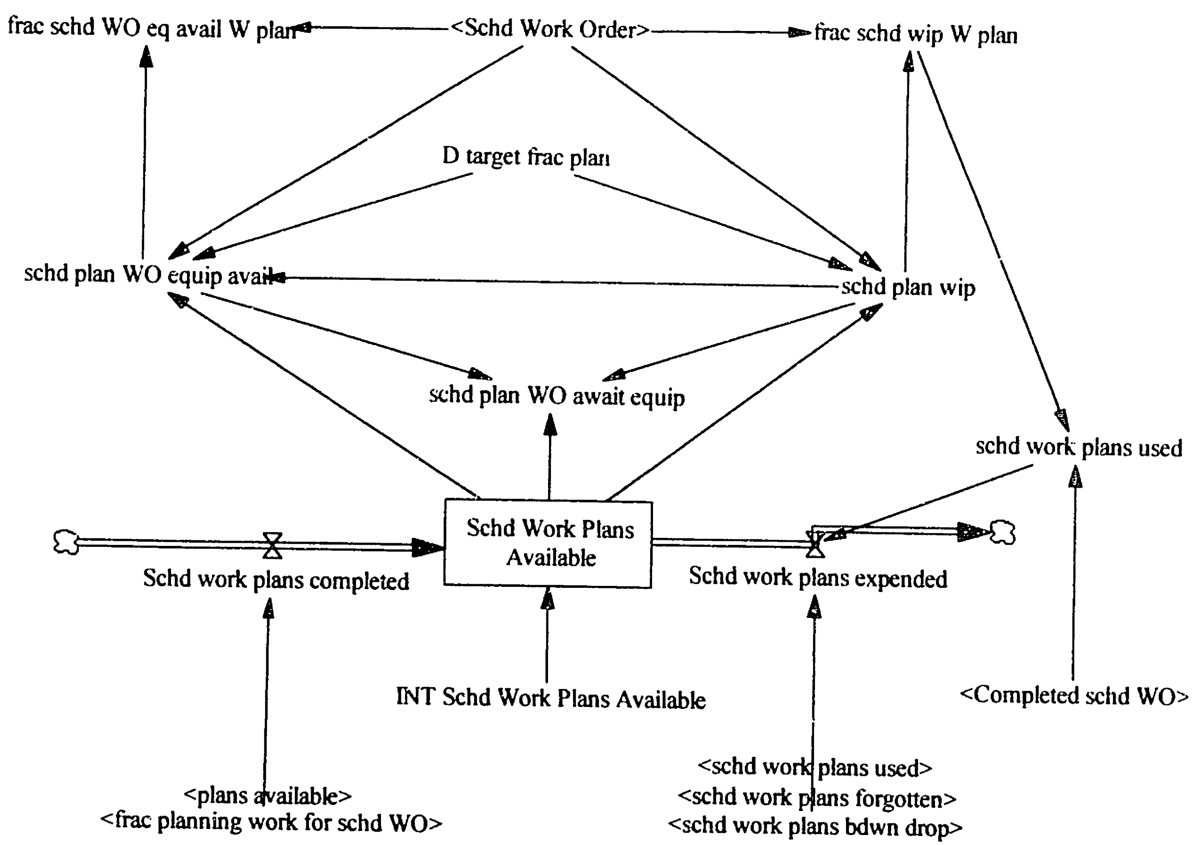
View 4: Defect Flow 2



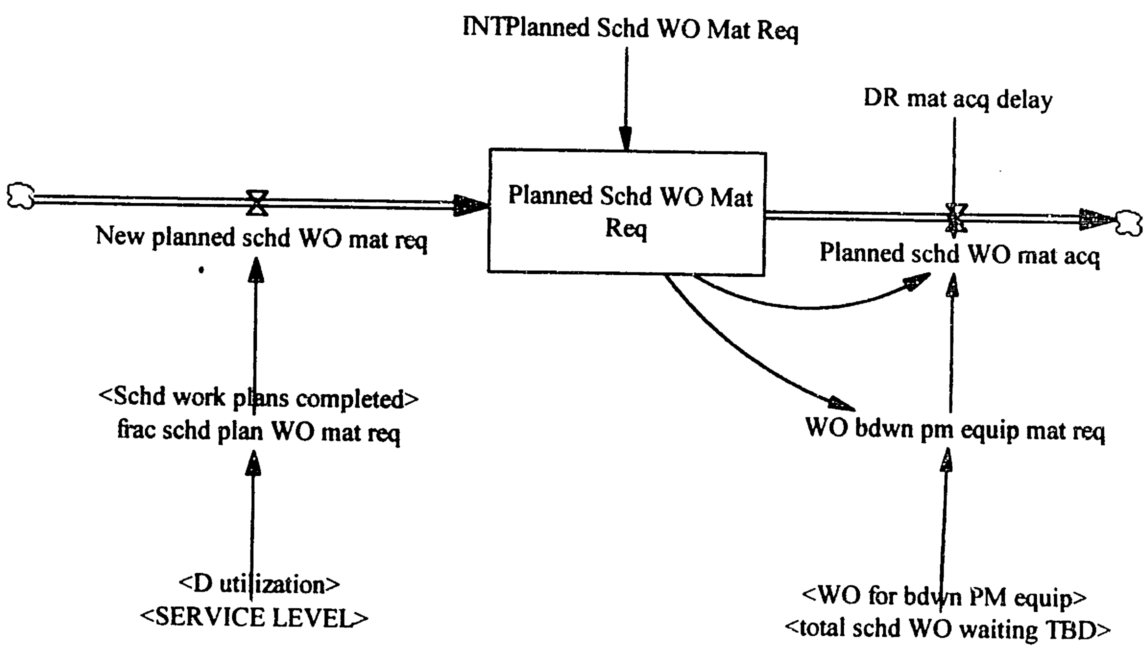
View 5: Defect Sources



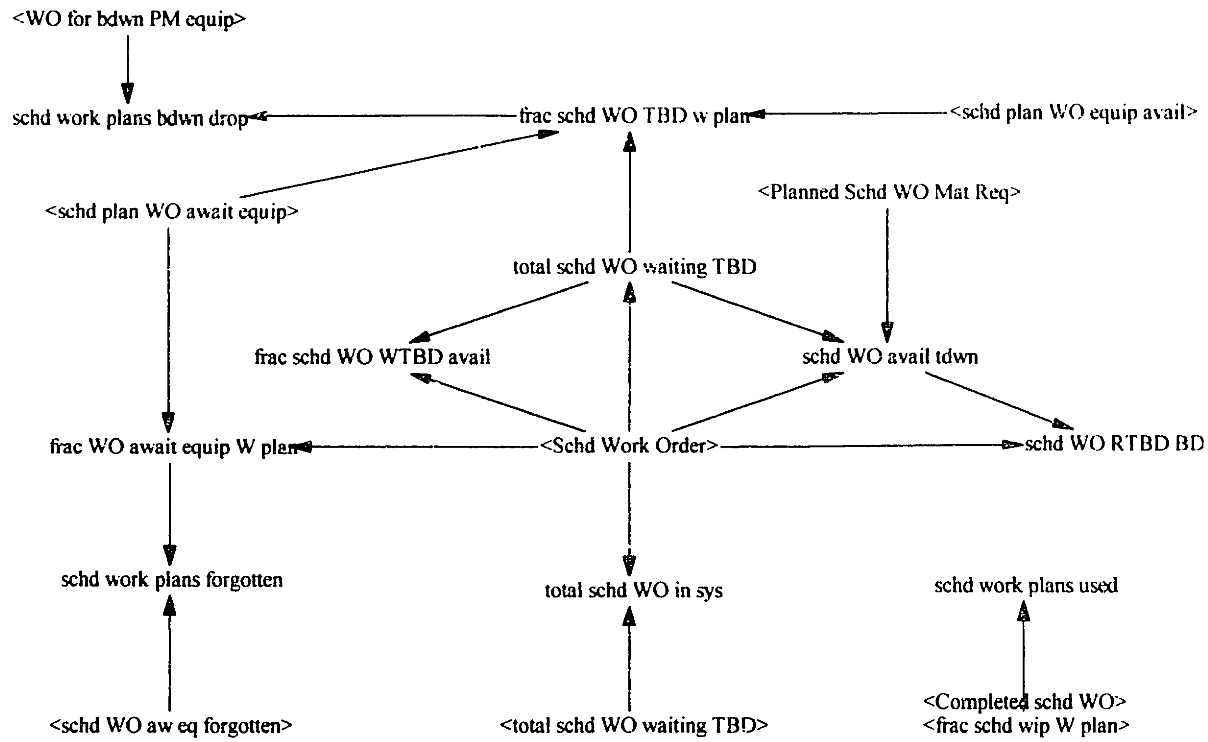
View 6: Learning Curve



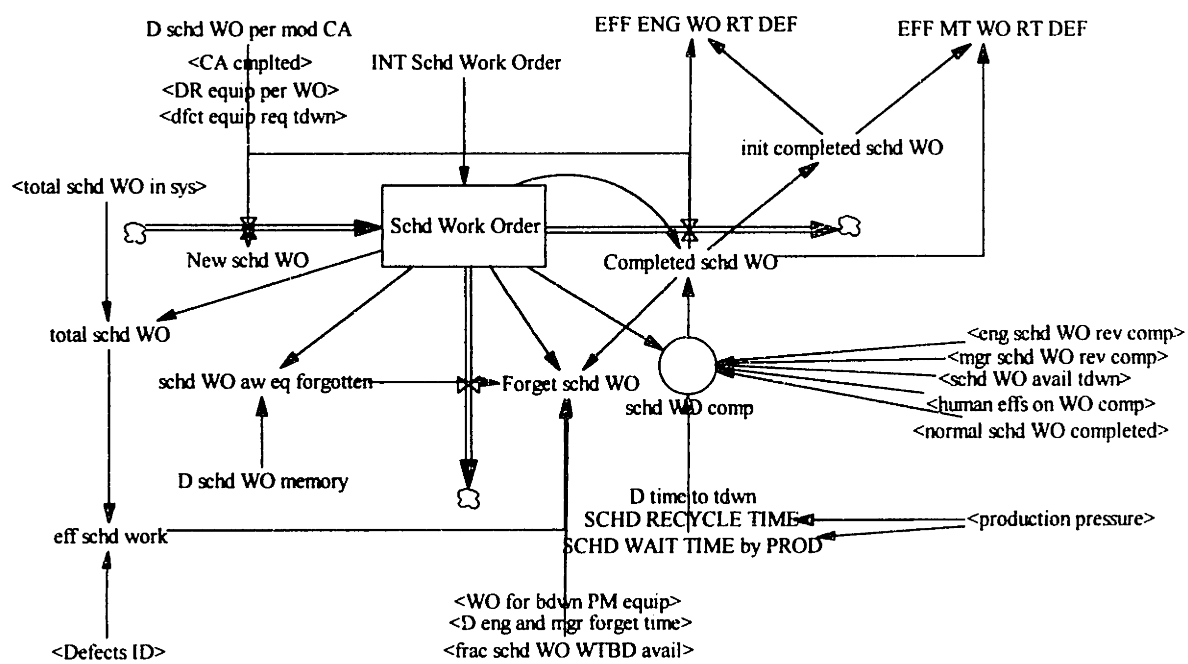
View 7: Scheduled Work Order 1



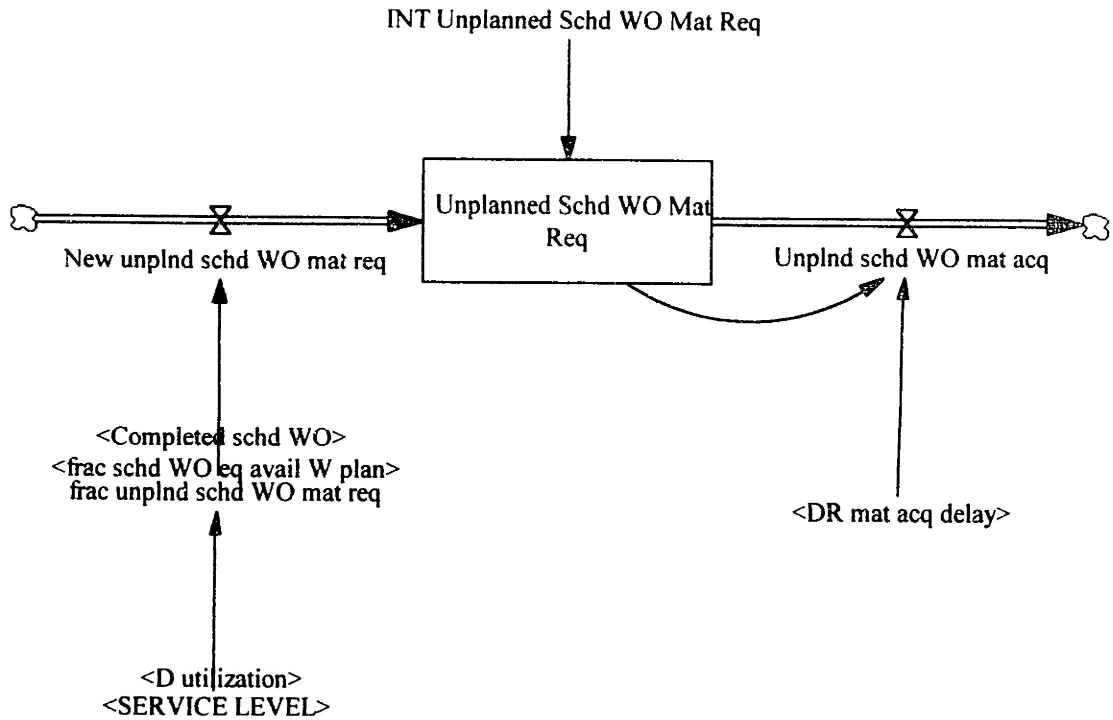
View 8: Scheduled Work Order 2



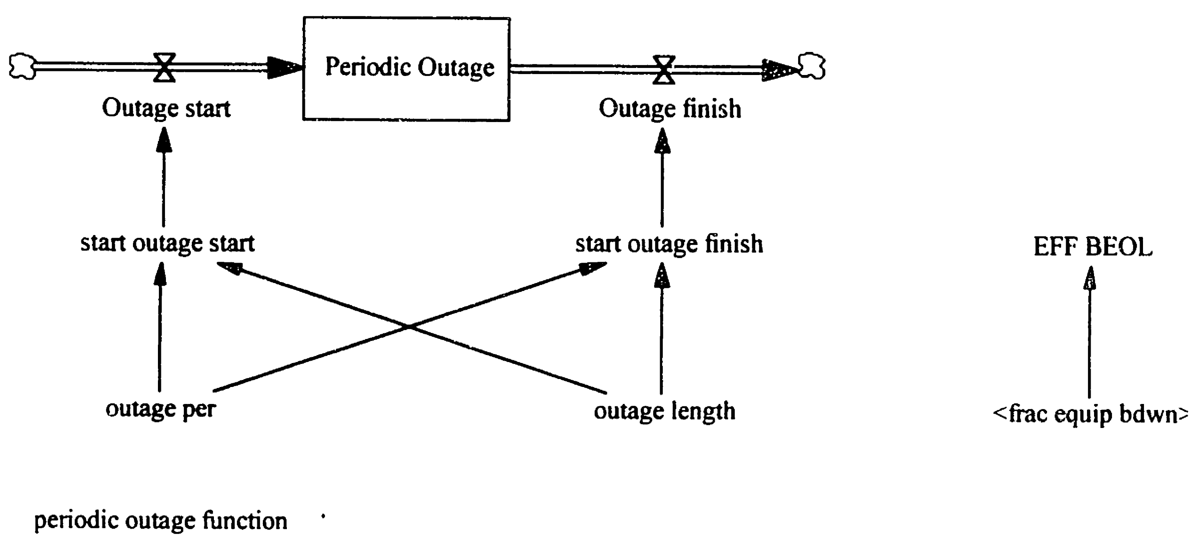
View 9: Scheduled Work Order 3



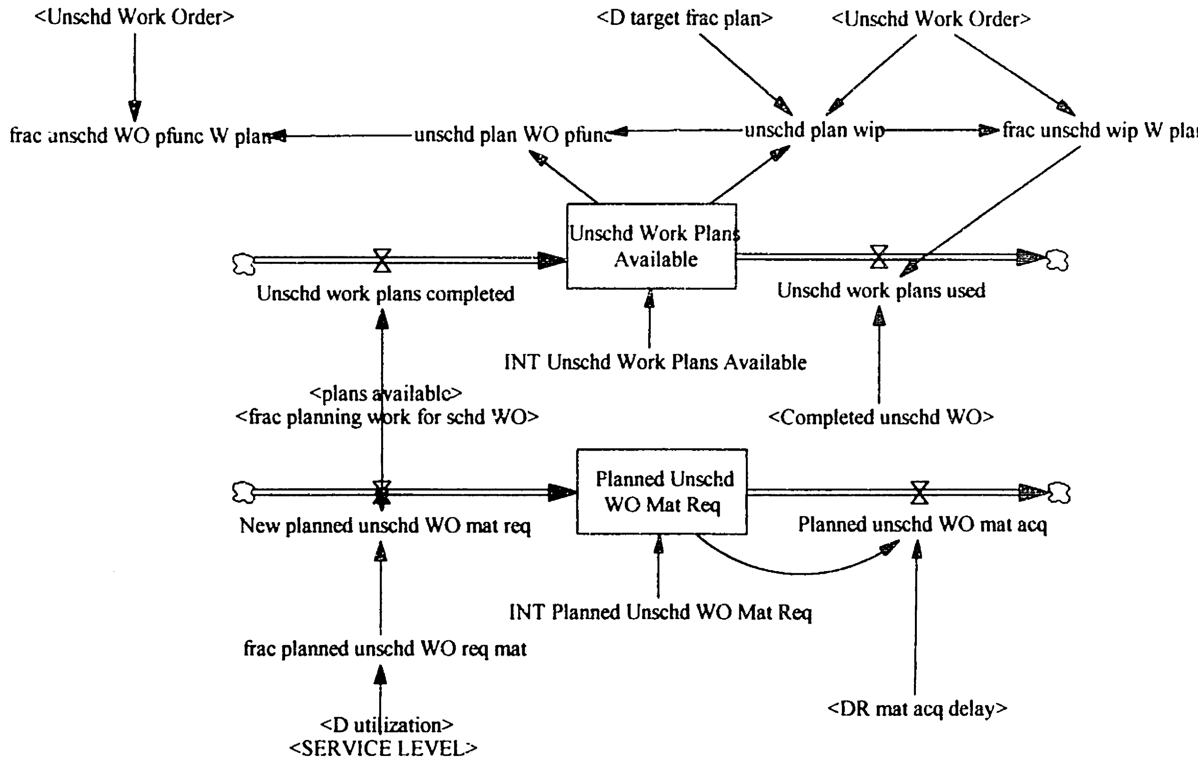
View 10: Scheduled Work Order 4



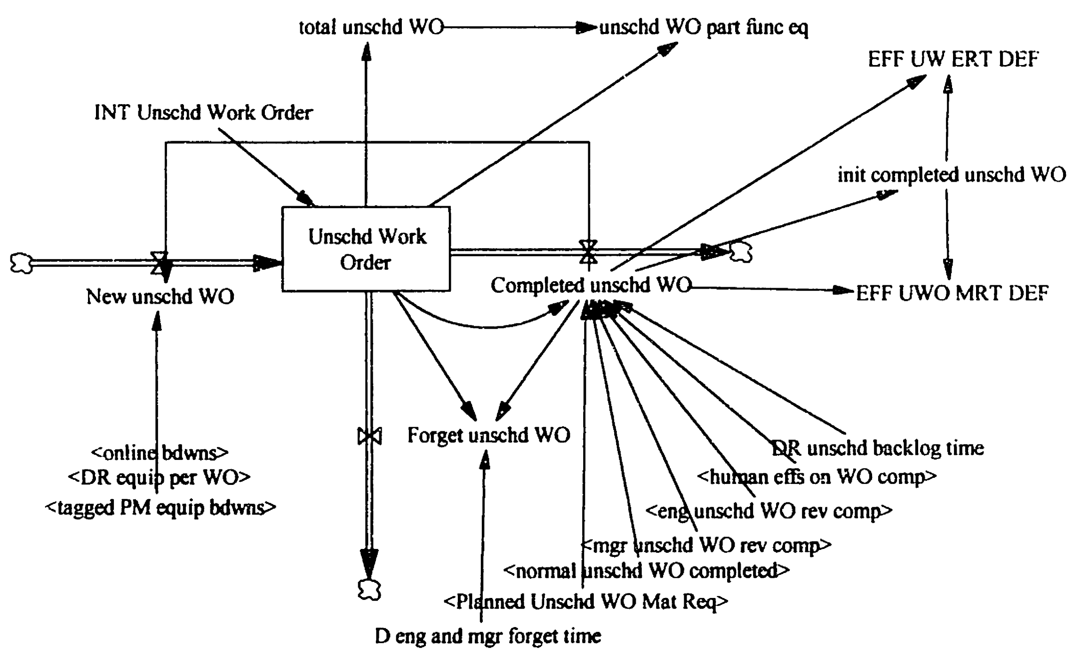
View 11: Scheduled Work Order 5



View 12: Periodic Outage



View 13: Unscheduled Work Order 1



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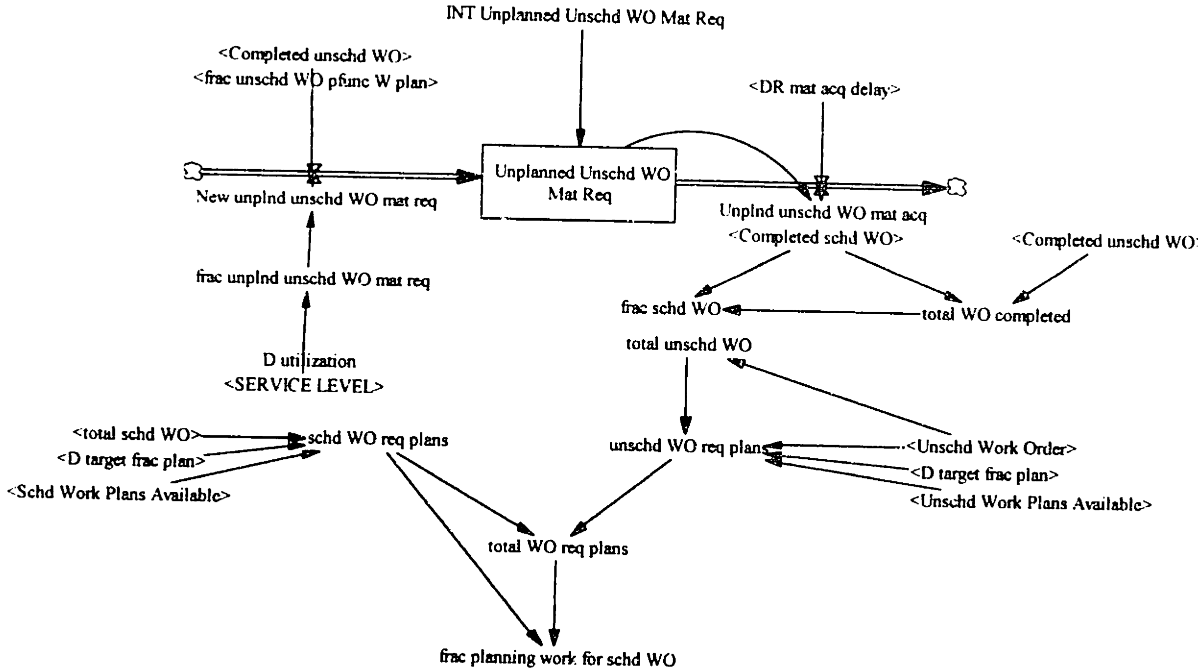
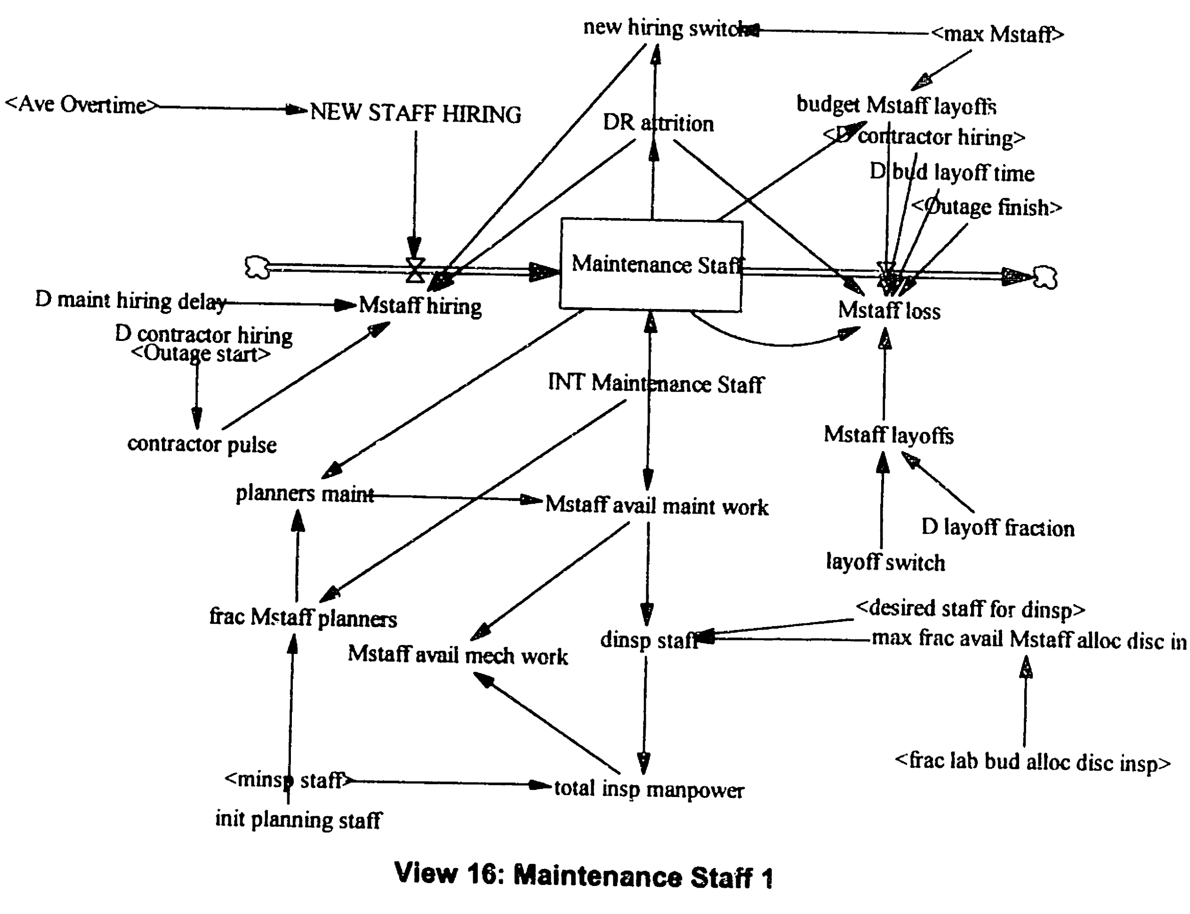
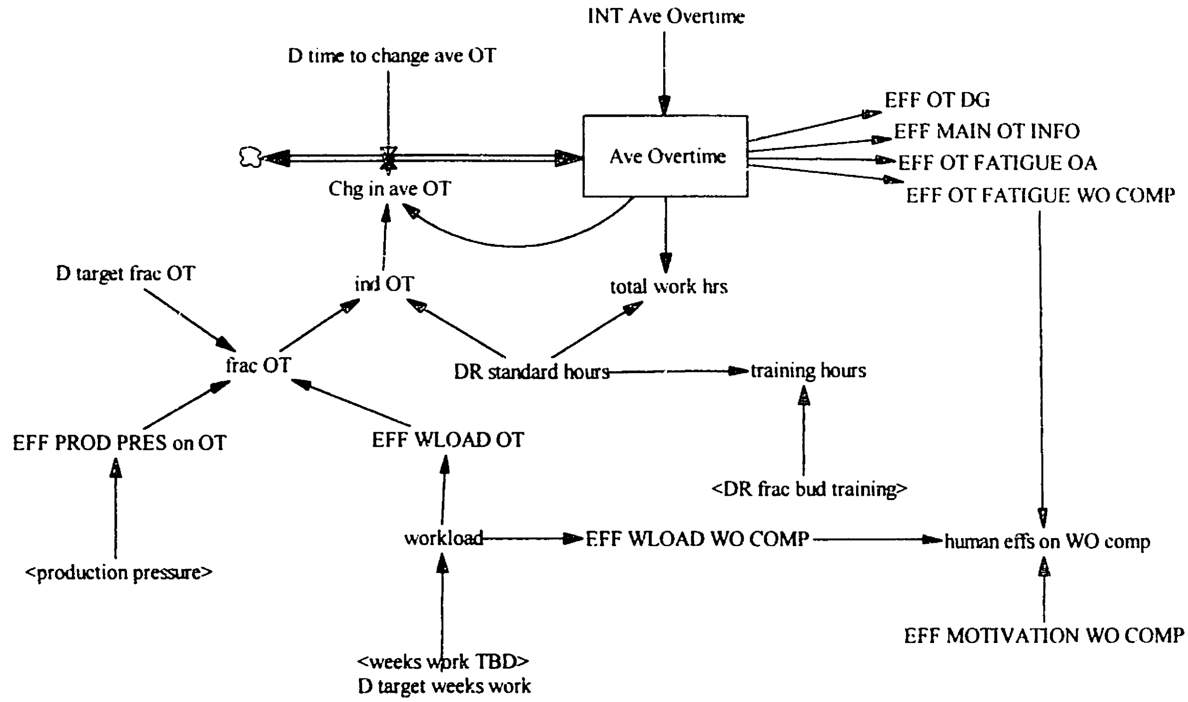


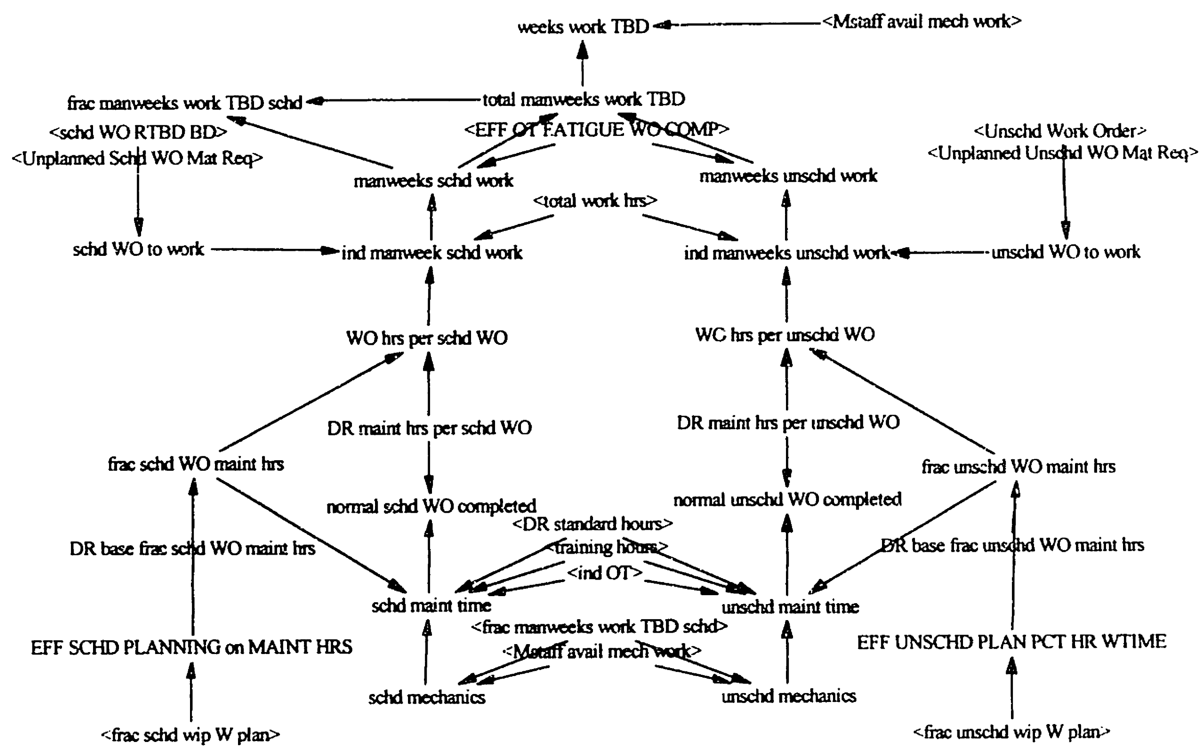
View 15: Unscheduled Work Order 3



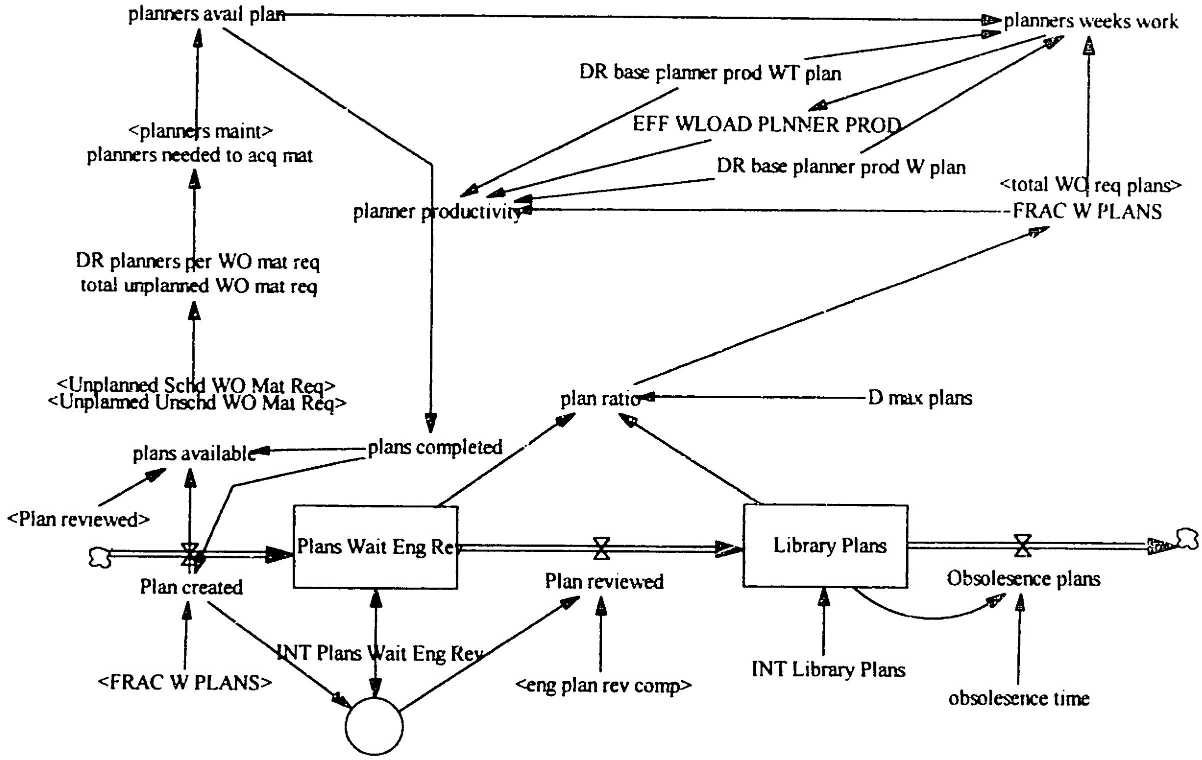
View 16: Maintenance Staff 1



View 17: Maintenance Staff 2



View 18: Mechanics Time Allocation



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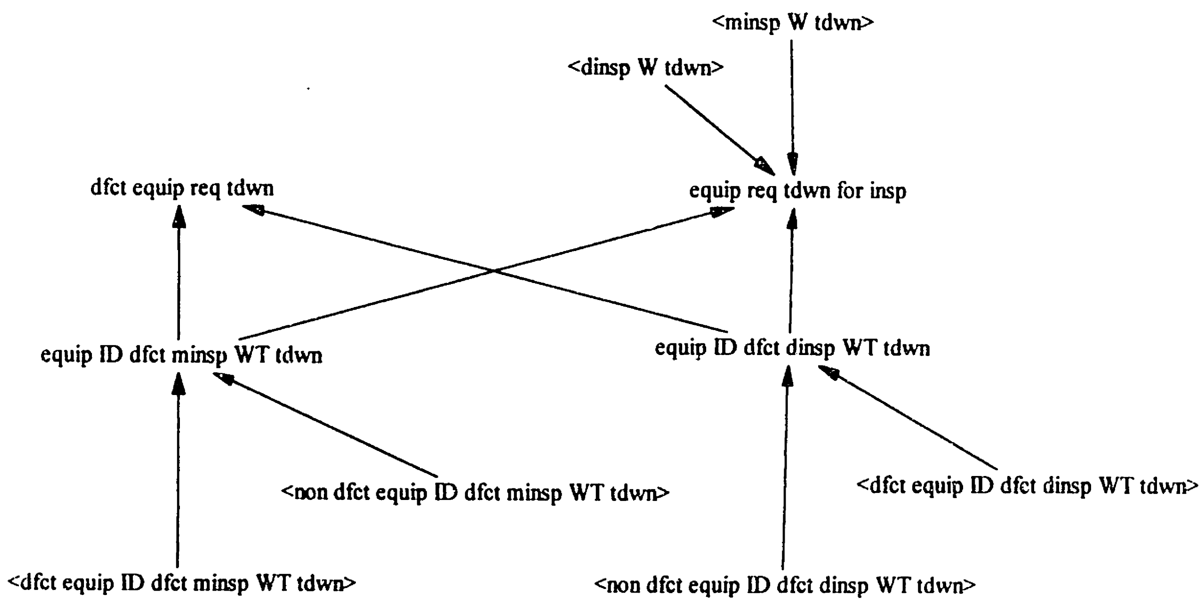

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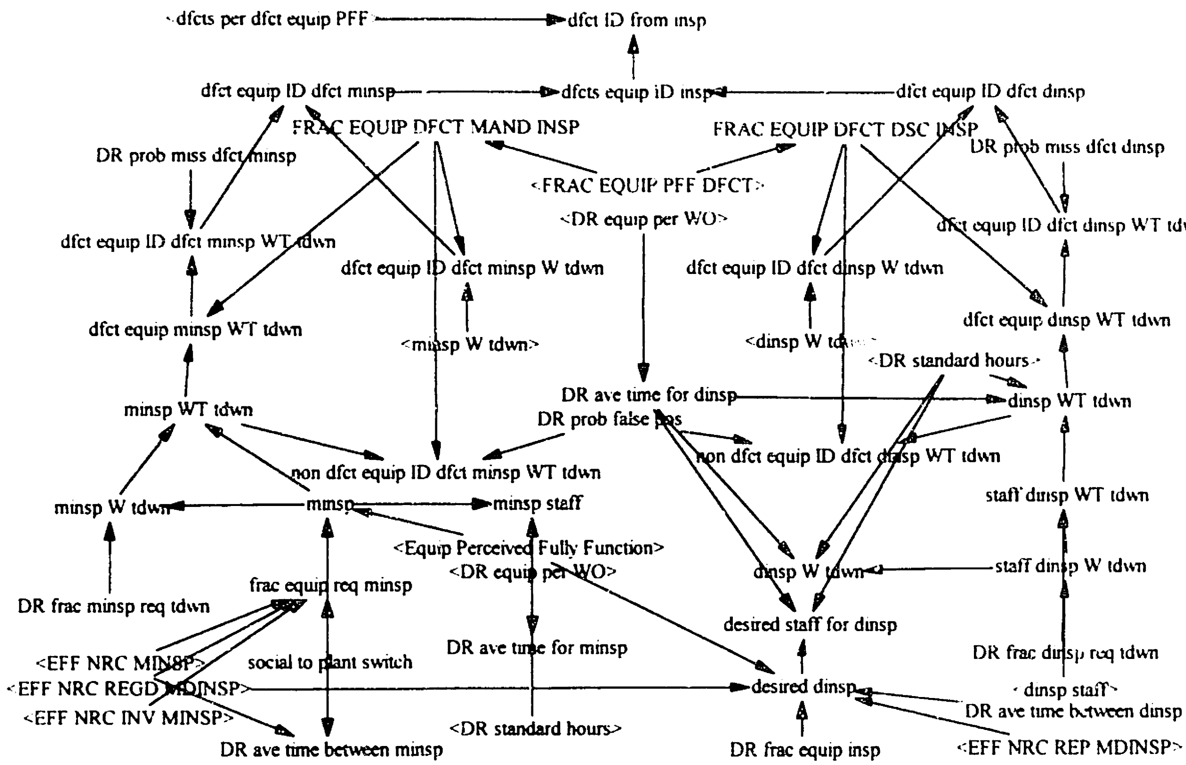
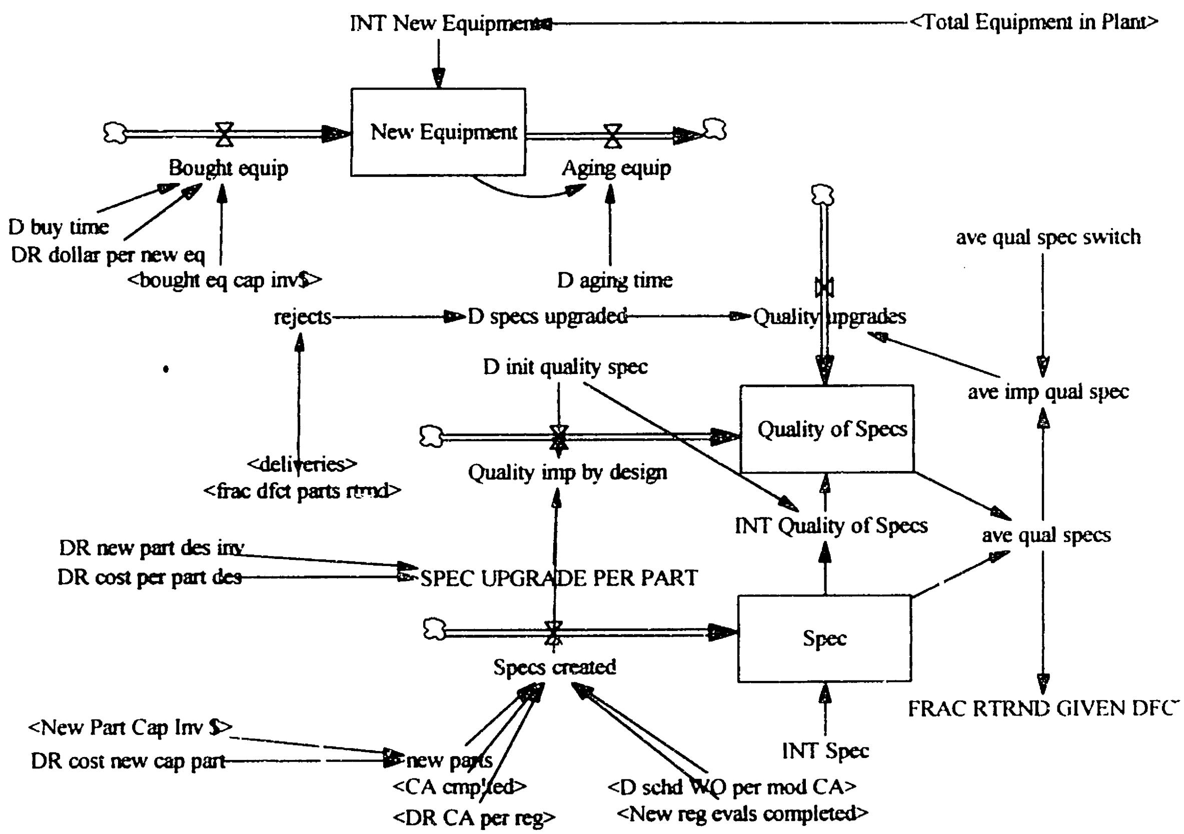
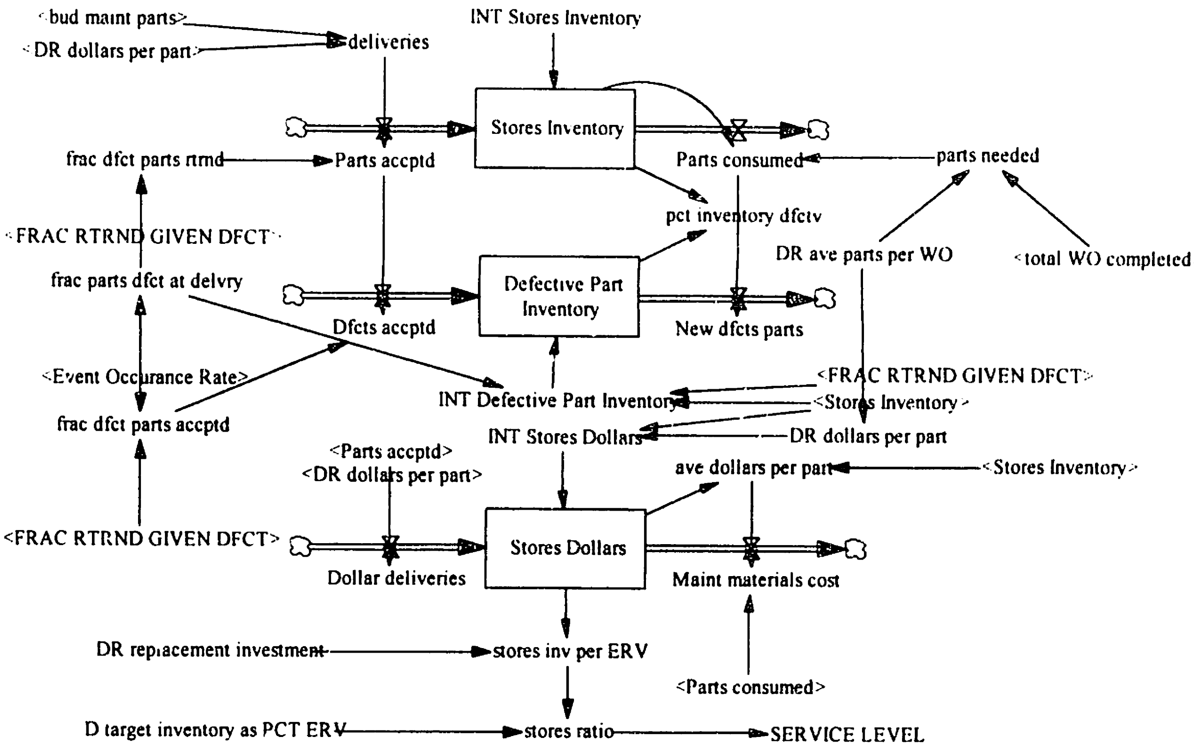


View 21: Inspections 2



View 22: Materials Specifications



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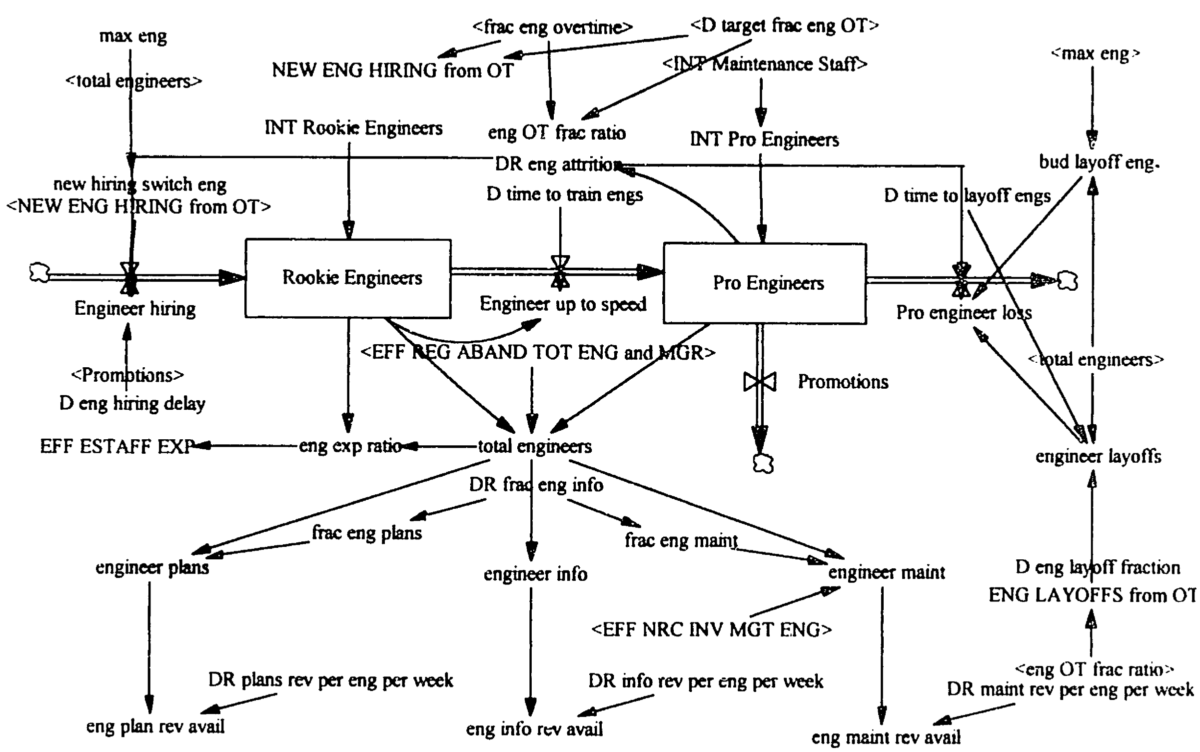
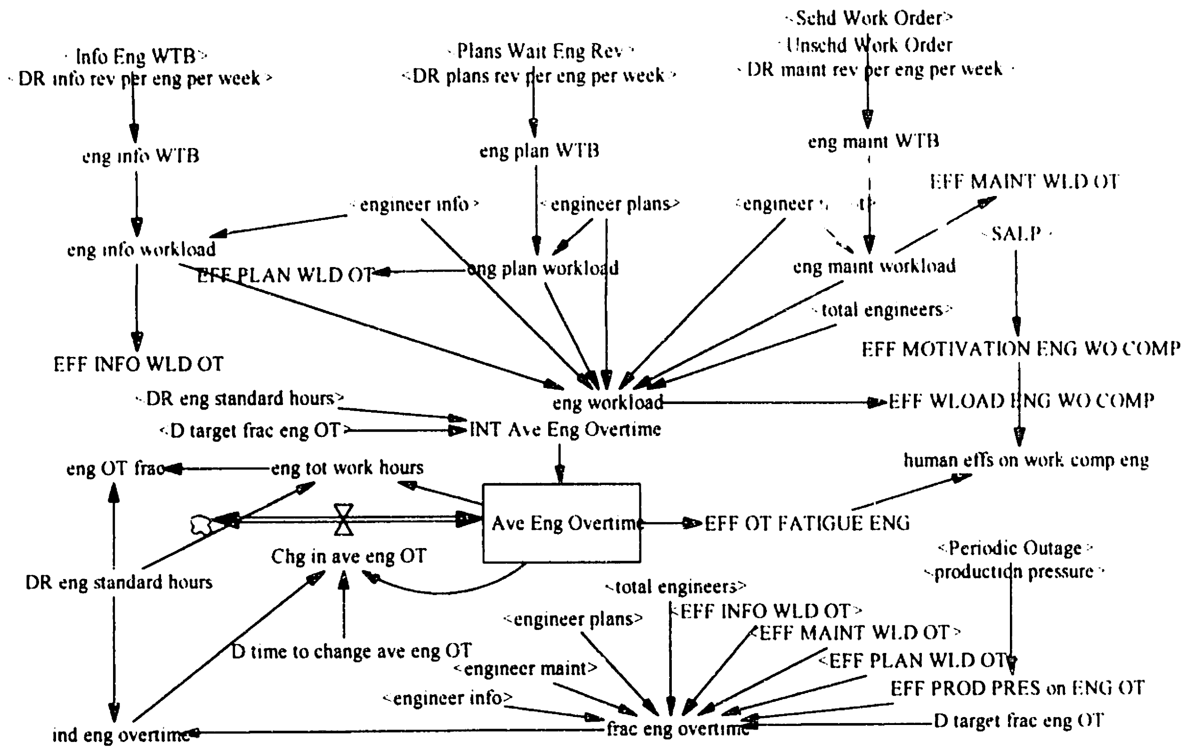


View 24: Engineers 1



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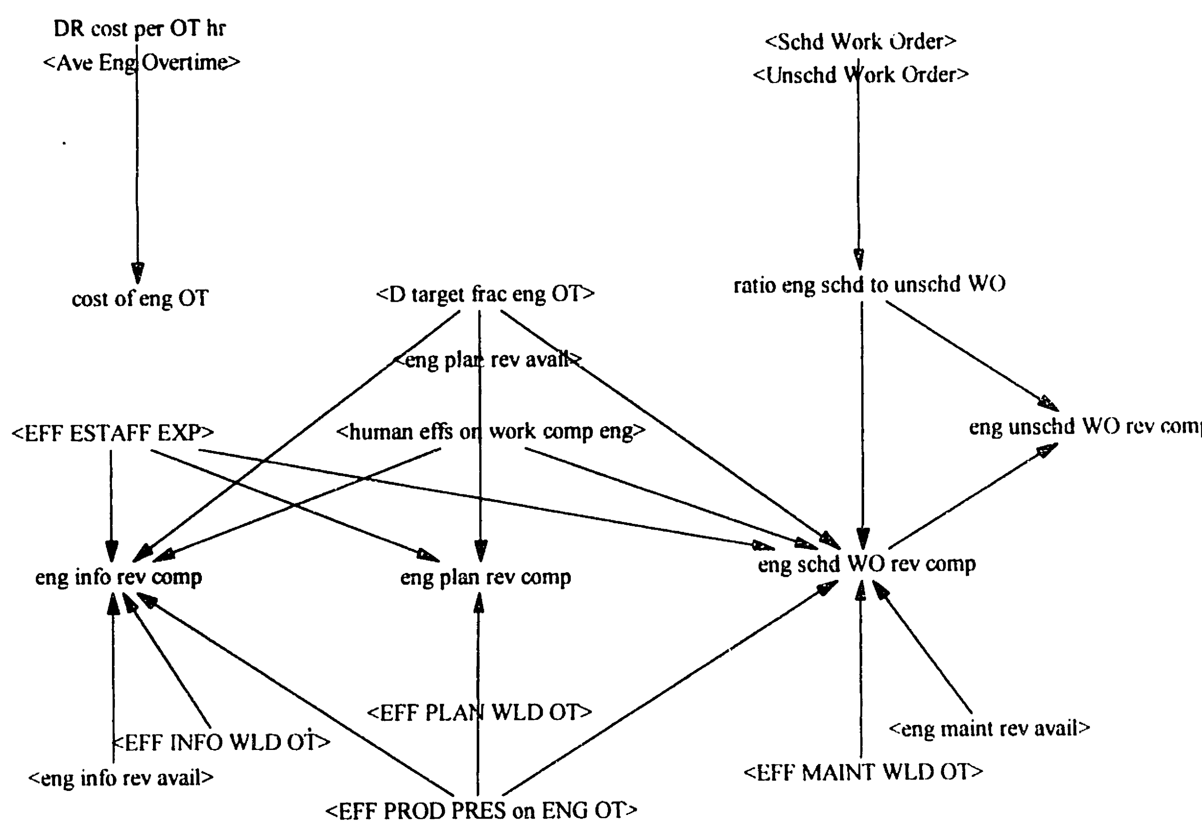

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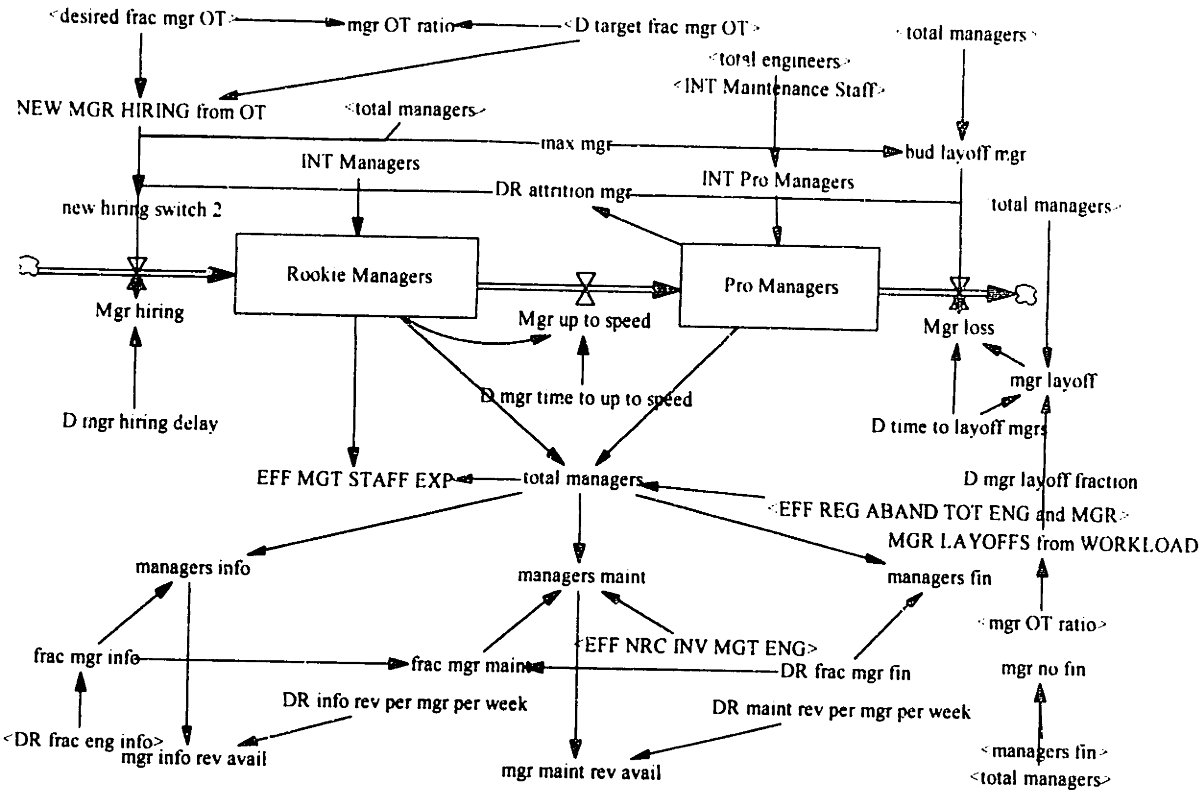

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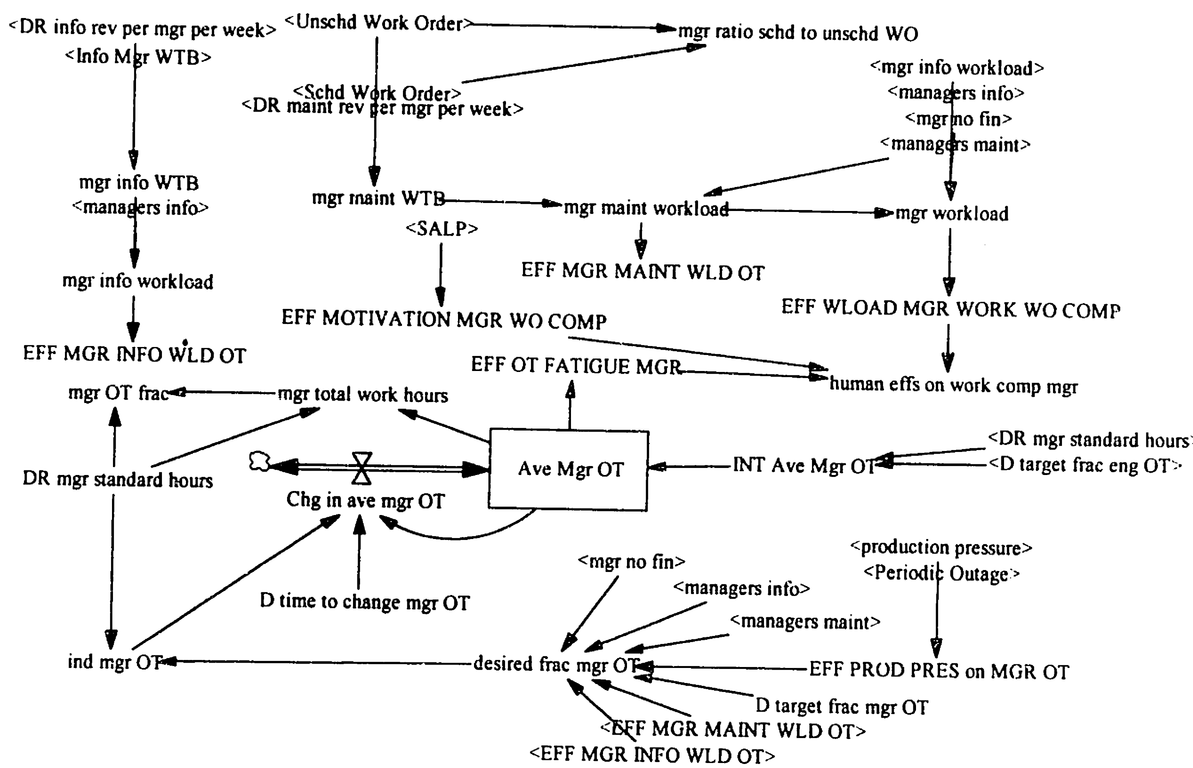

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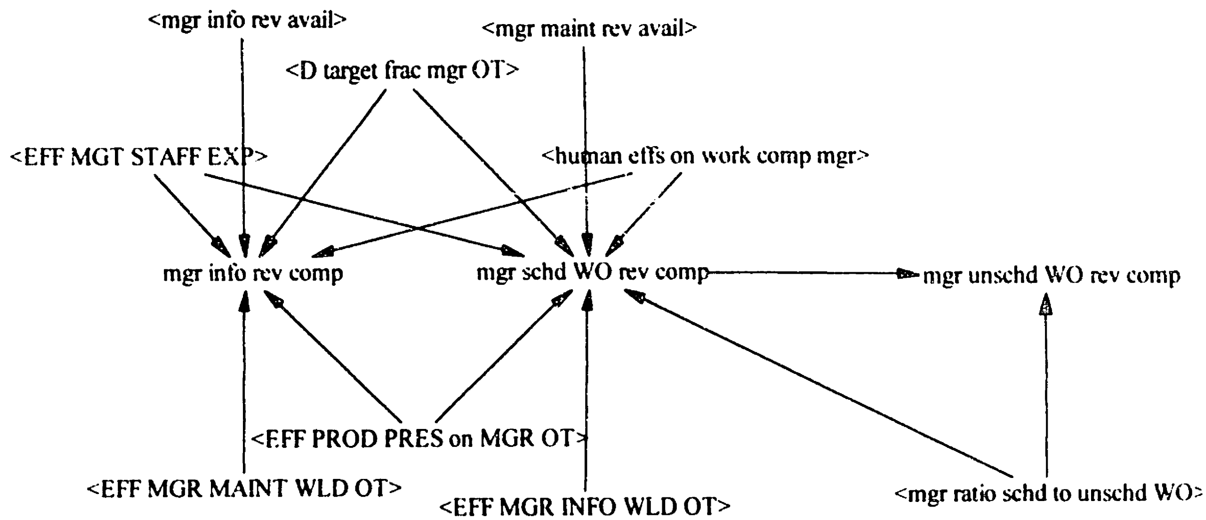
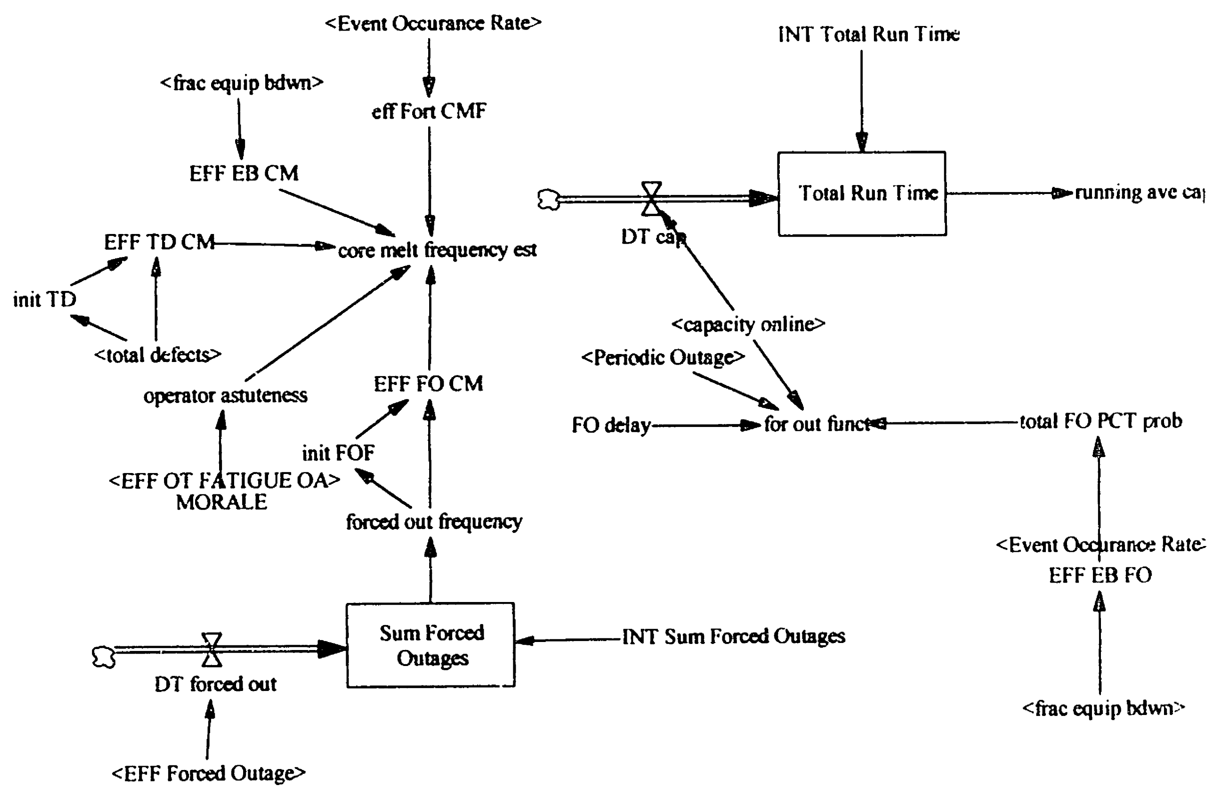


View 29: Manager 3



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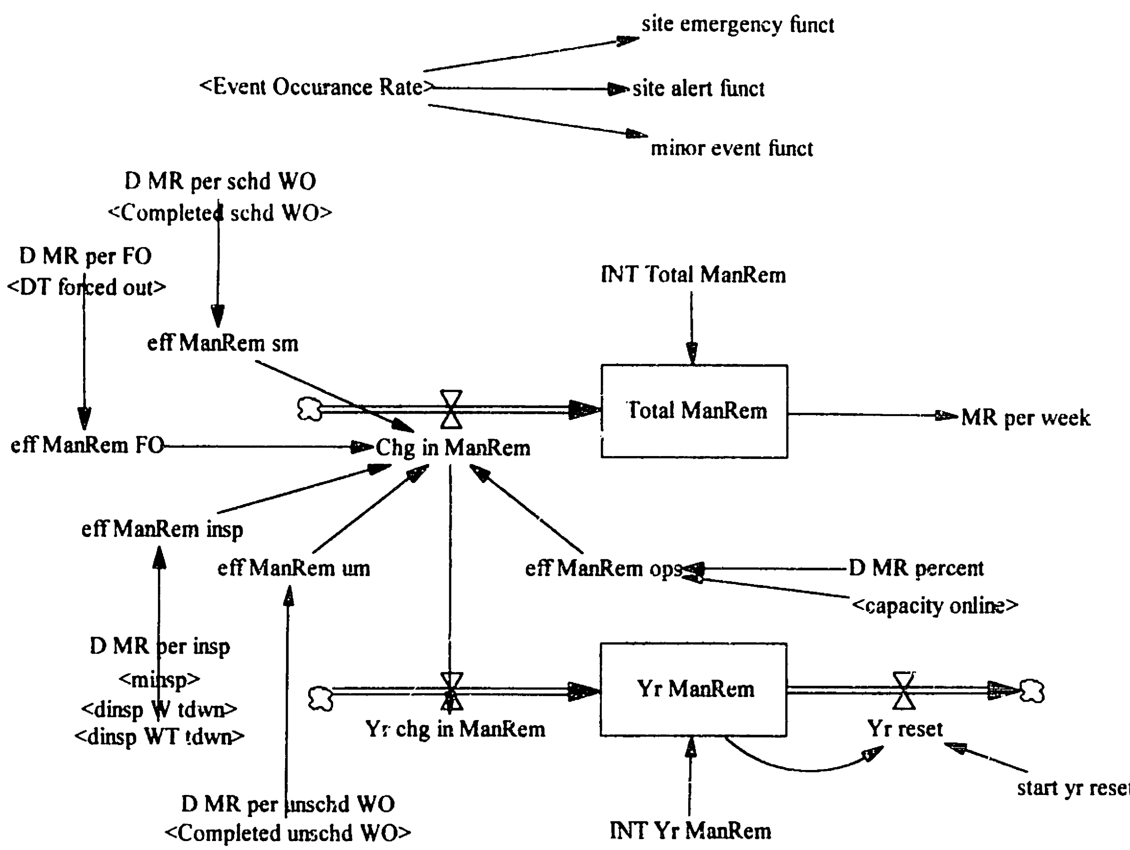
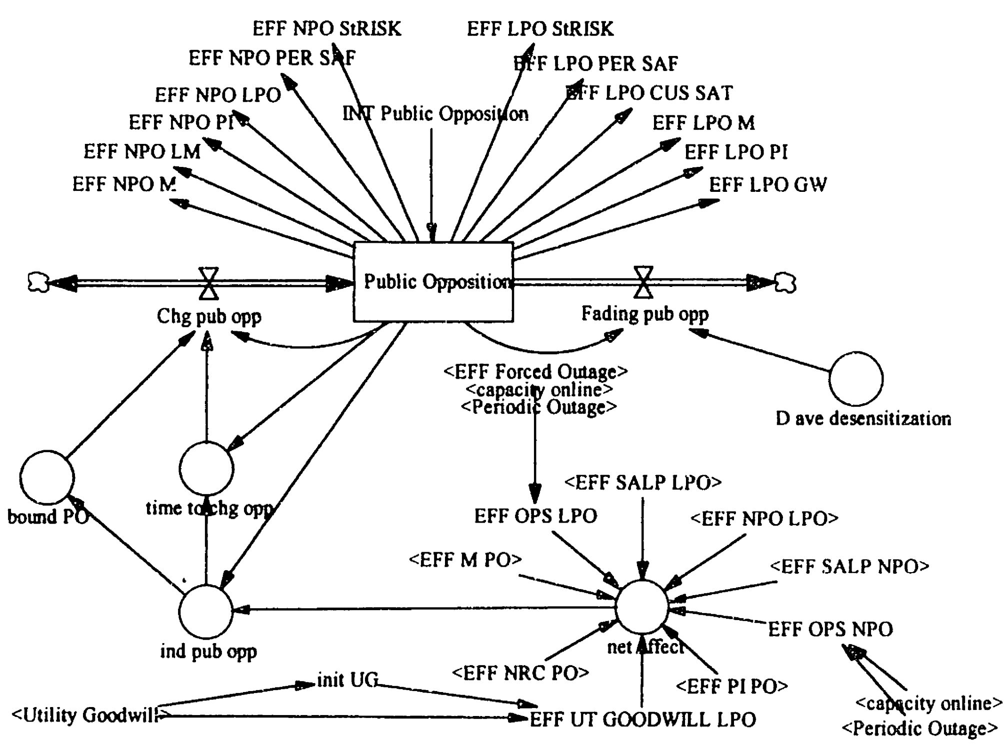
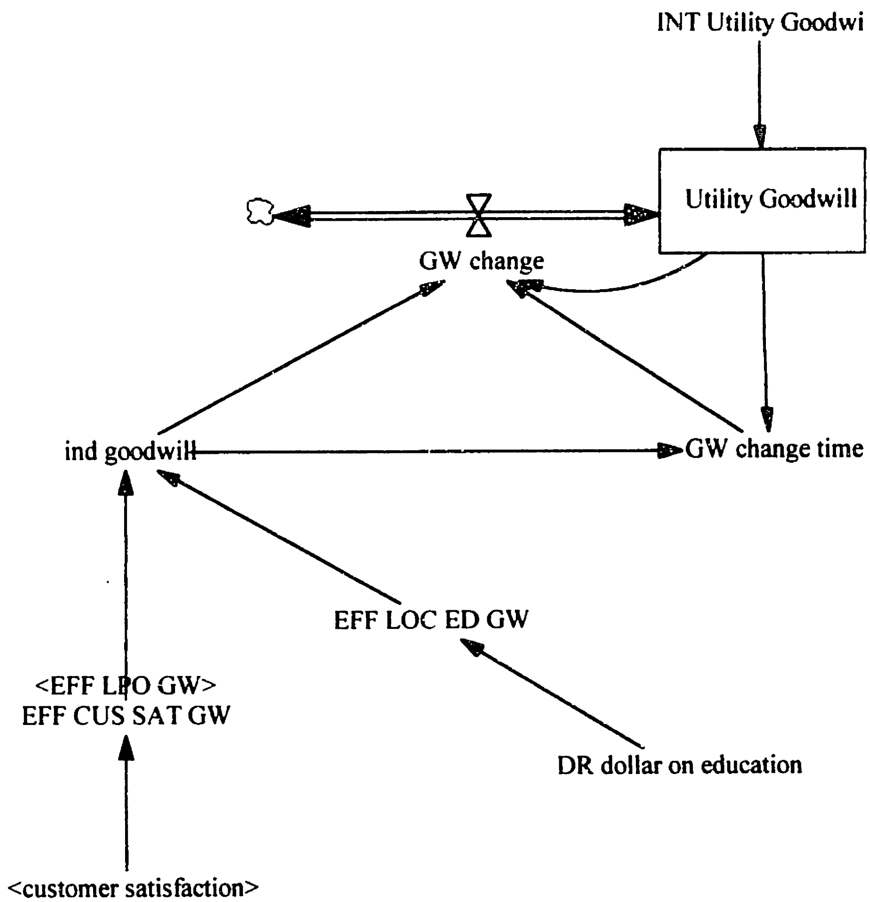


View 31: Safety 2



View 32: Public Concern 1



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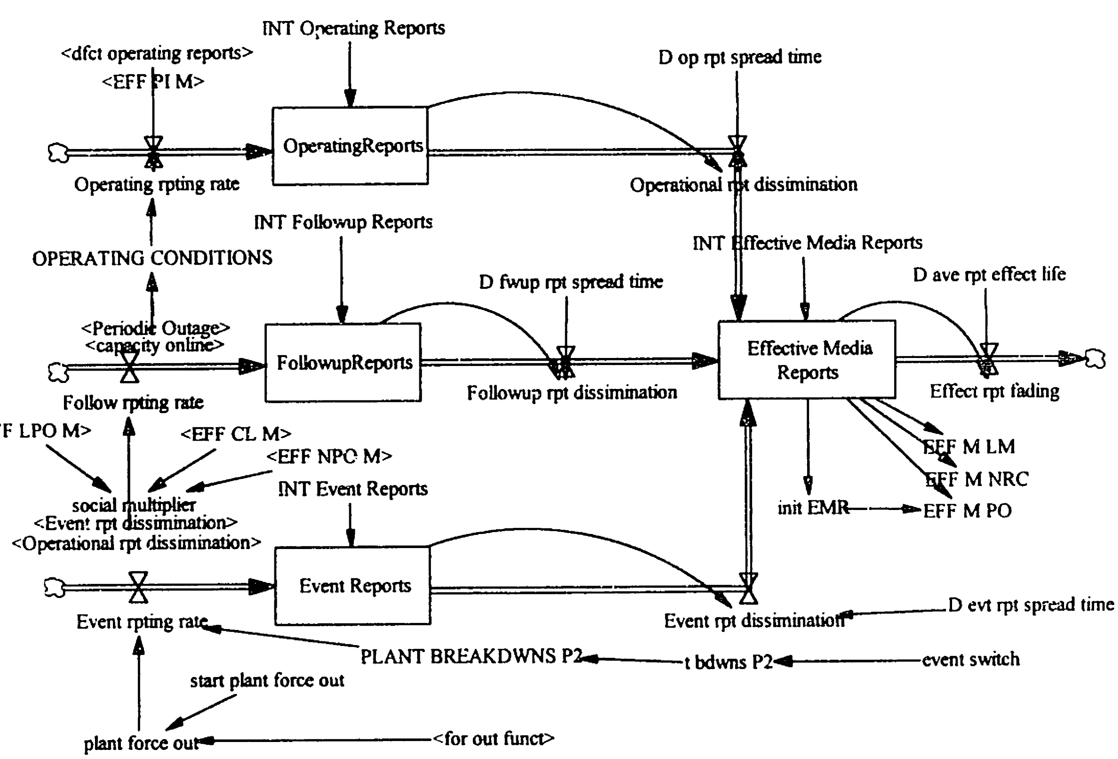
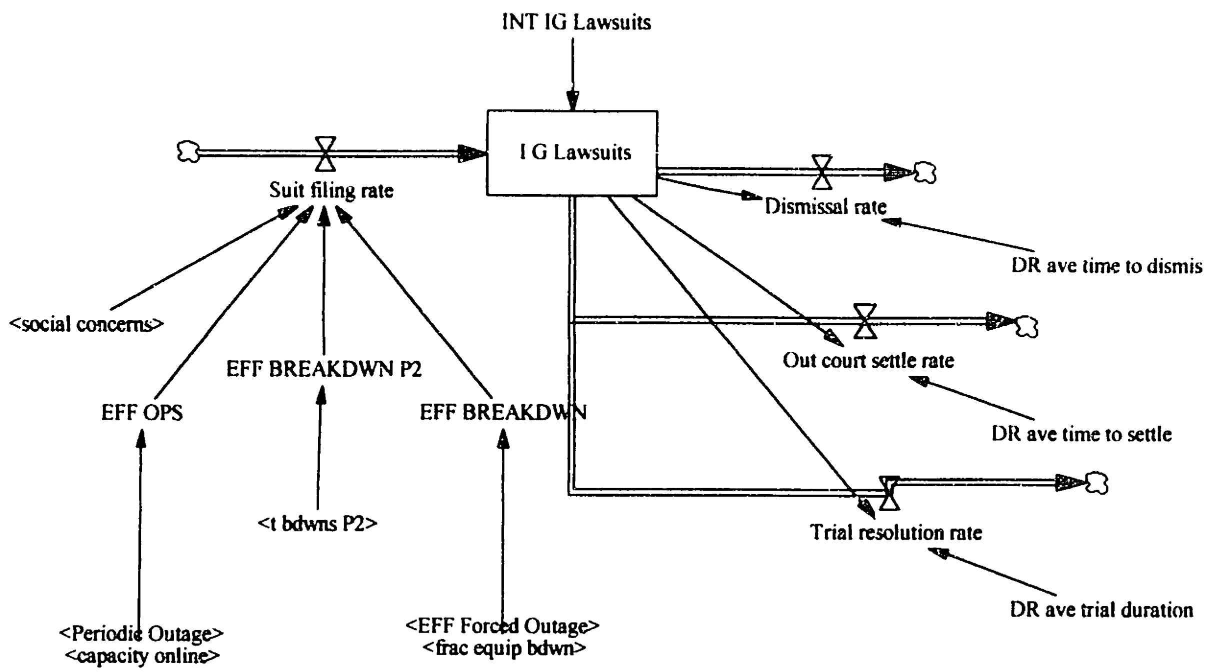
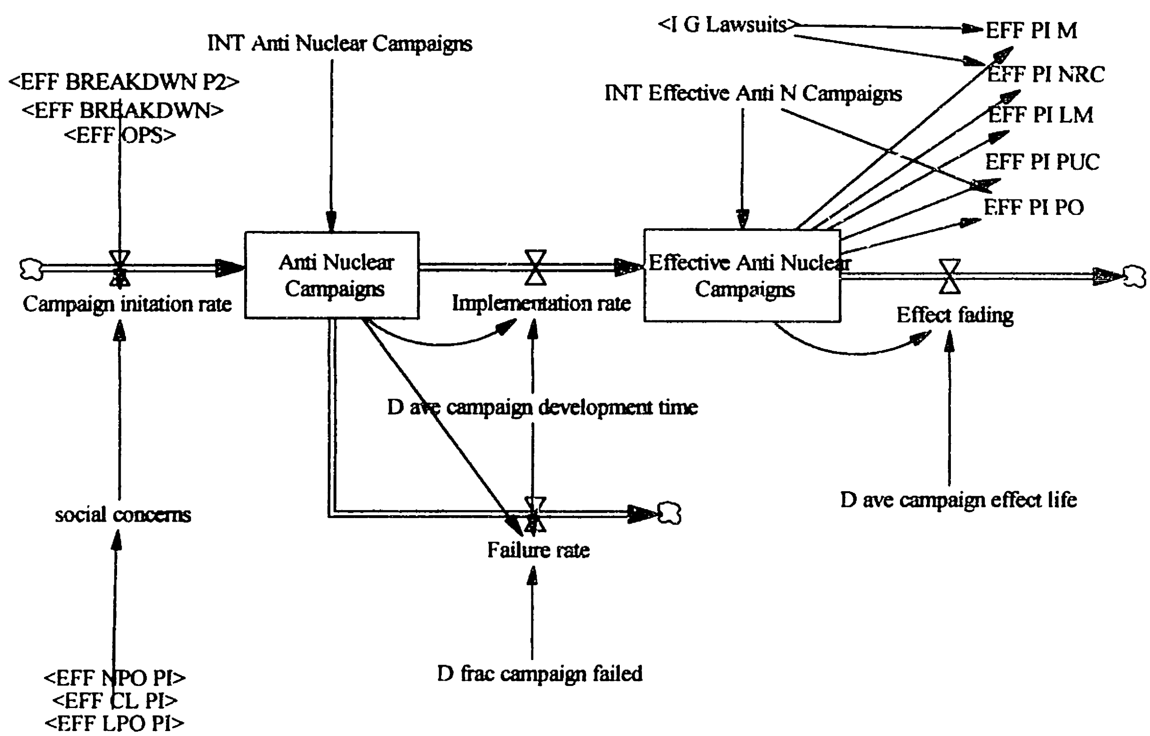


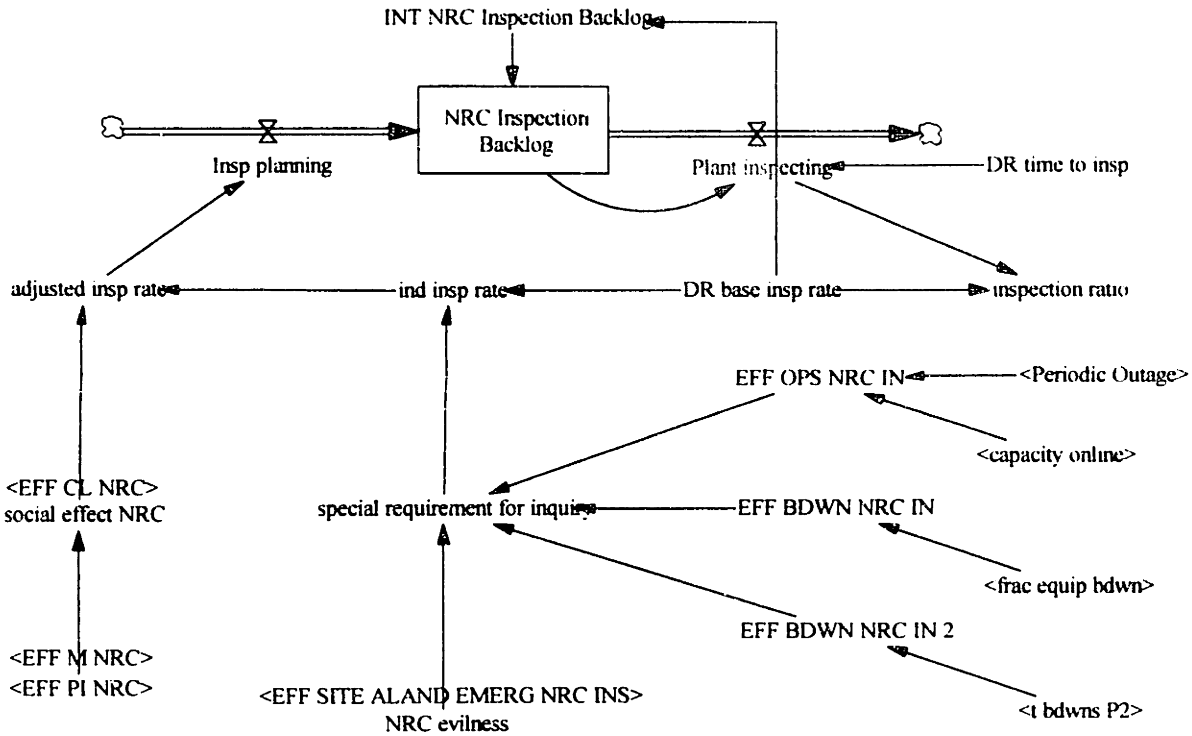
View 34: Media Coverage



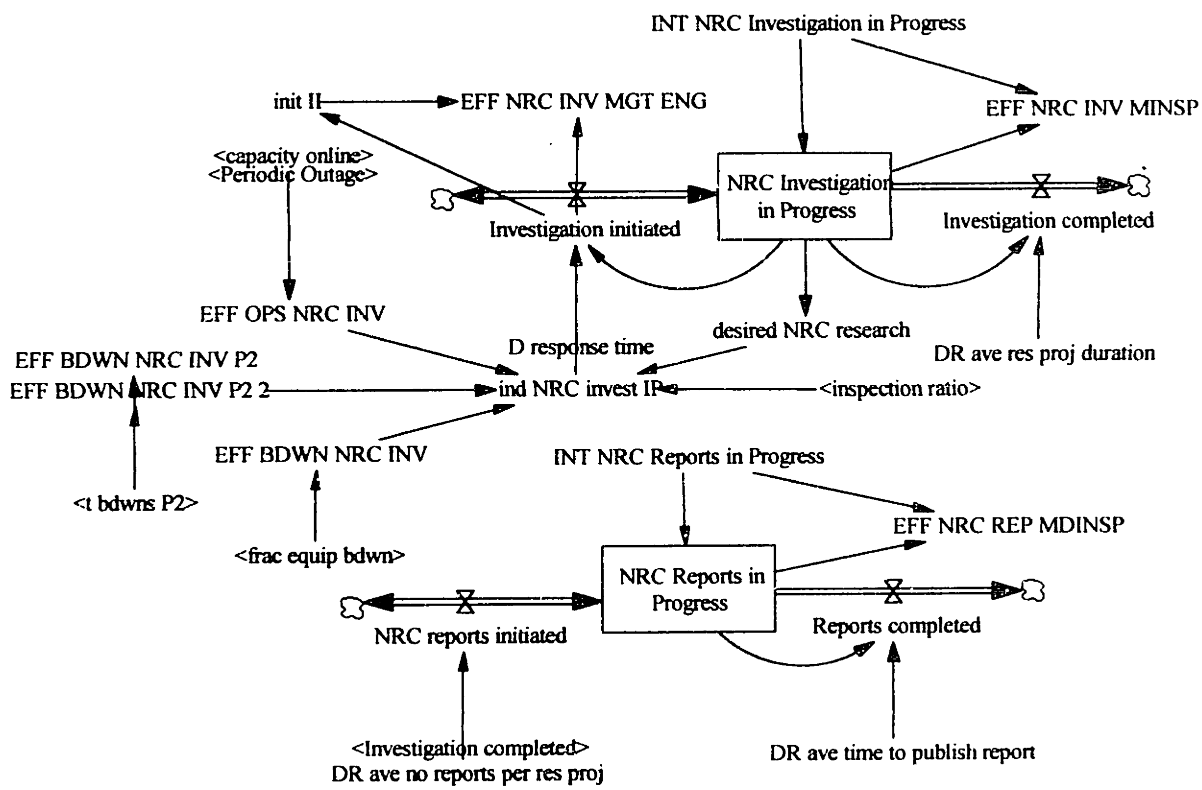
View 35: Interest Groups 1



View 36: Interest Groups 2



View 37: NRC 1



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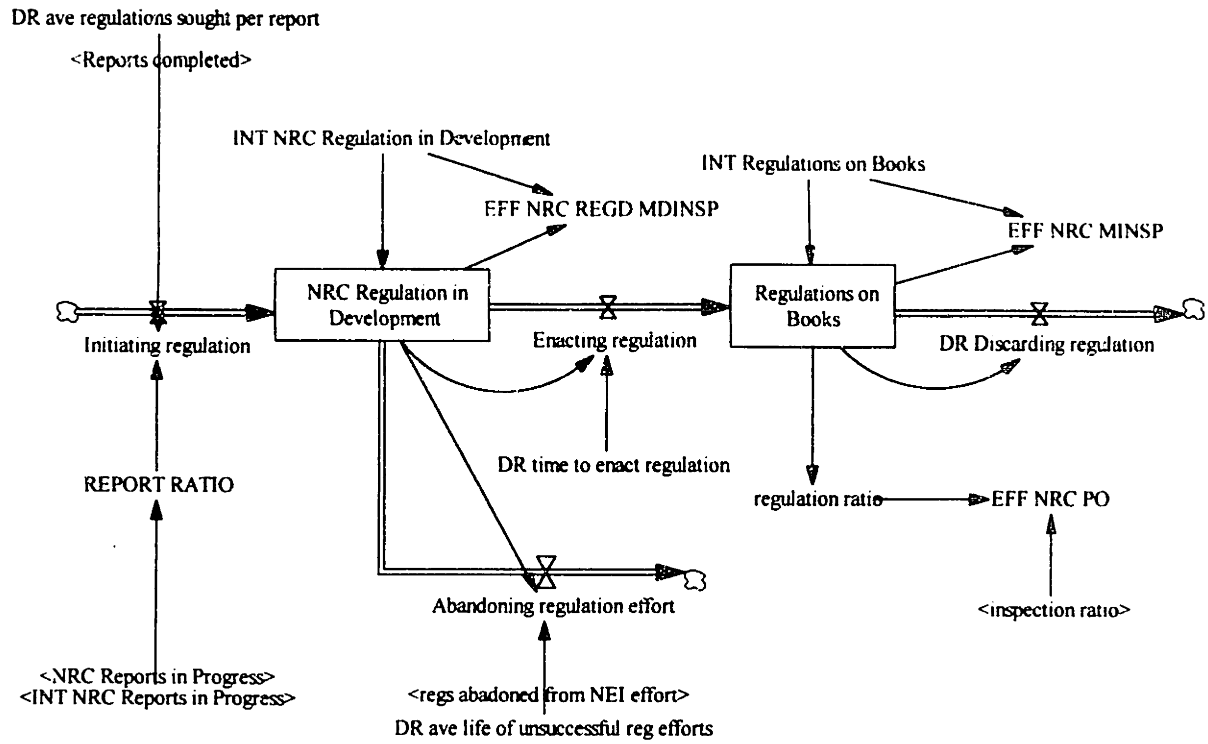

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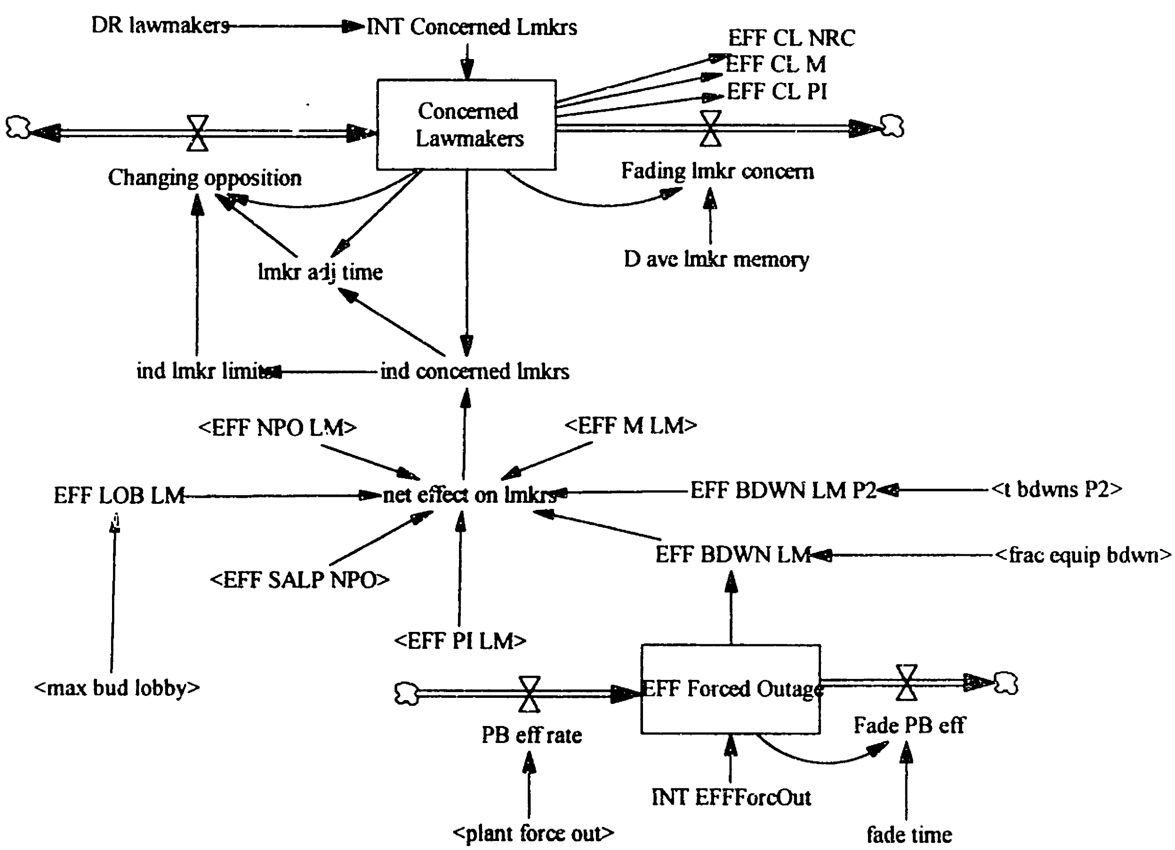
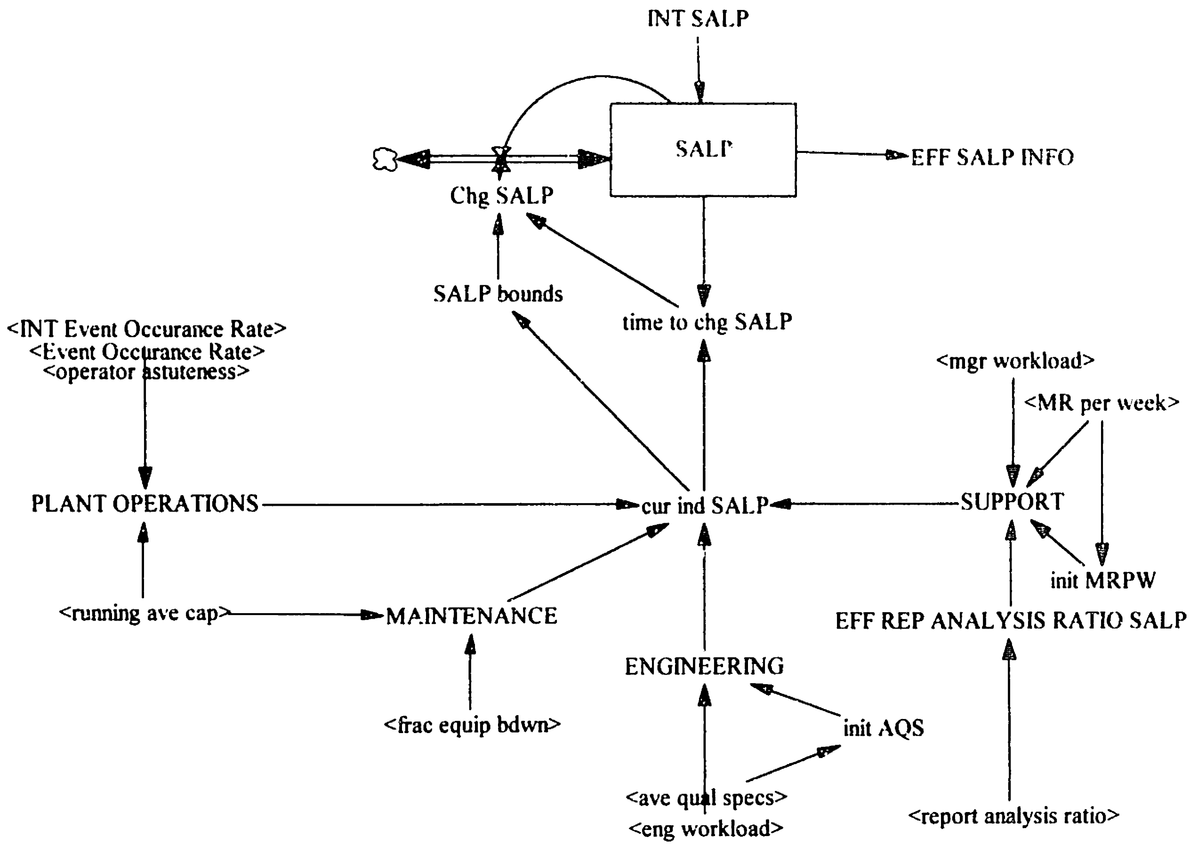
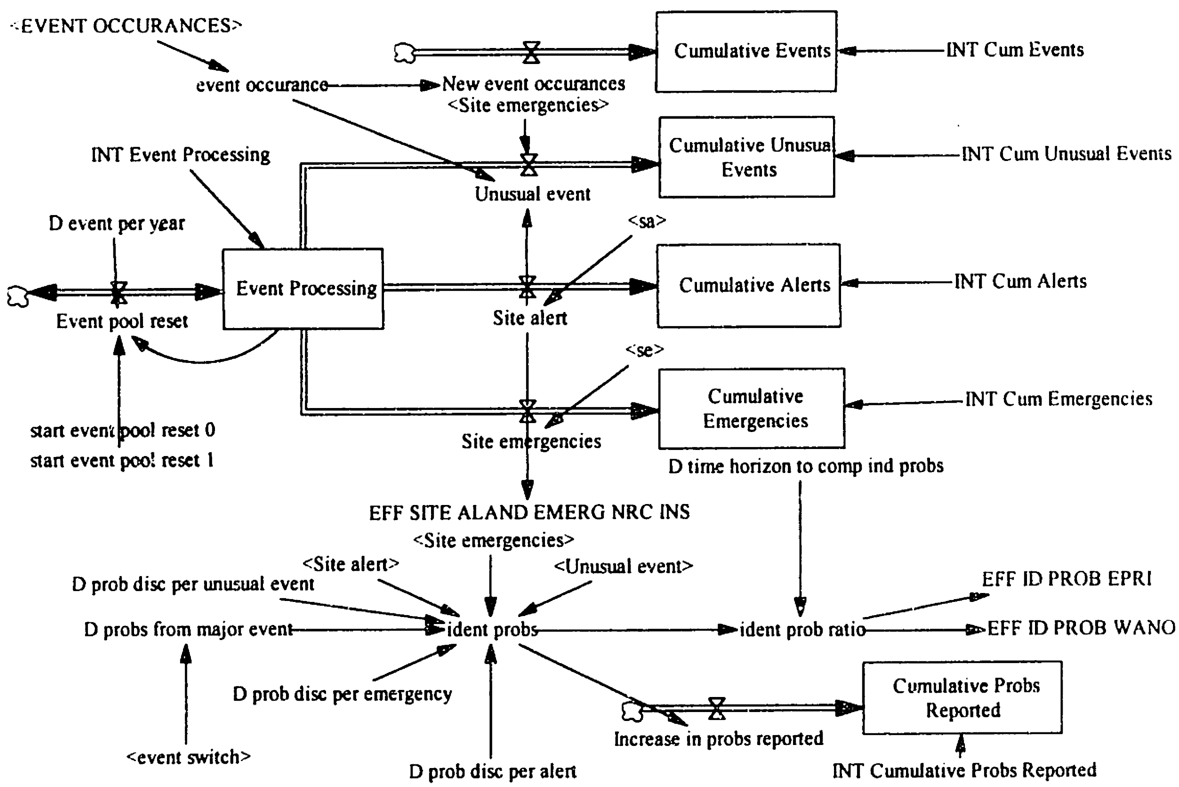


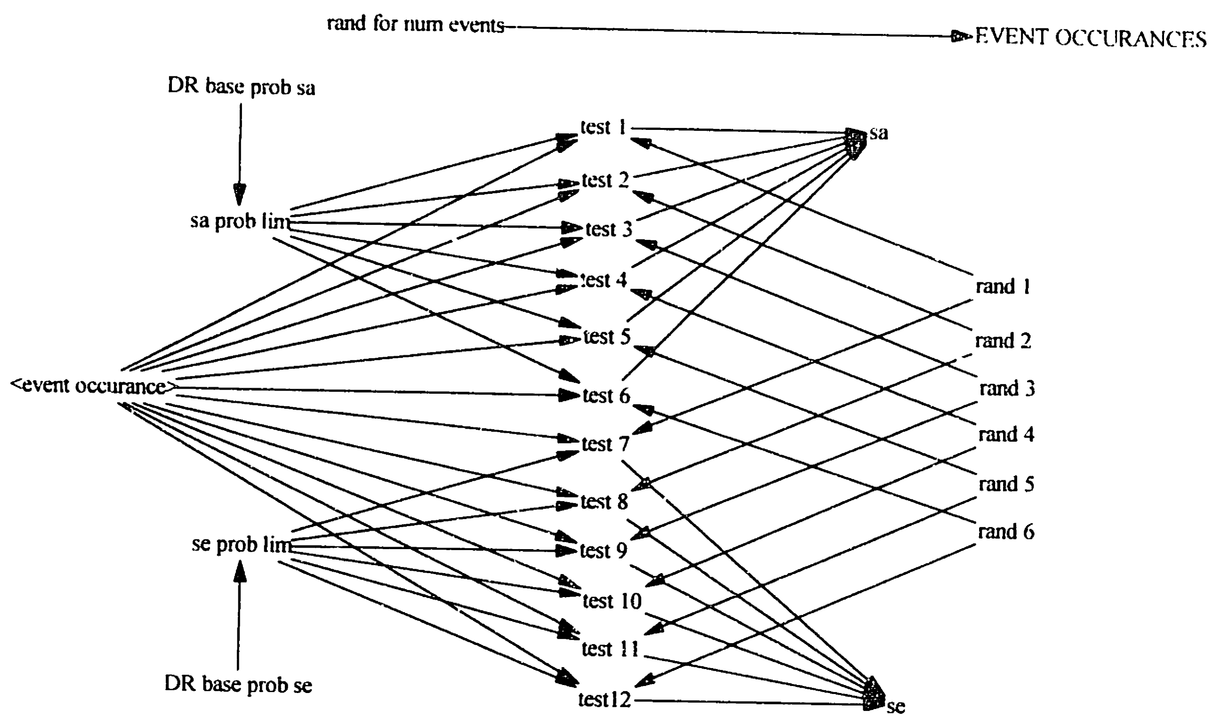
View 40: Congressional Concern



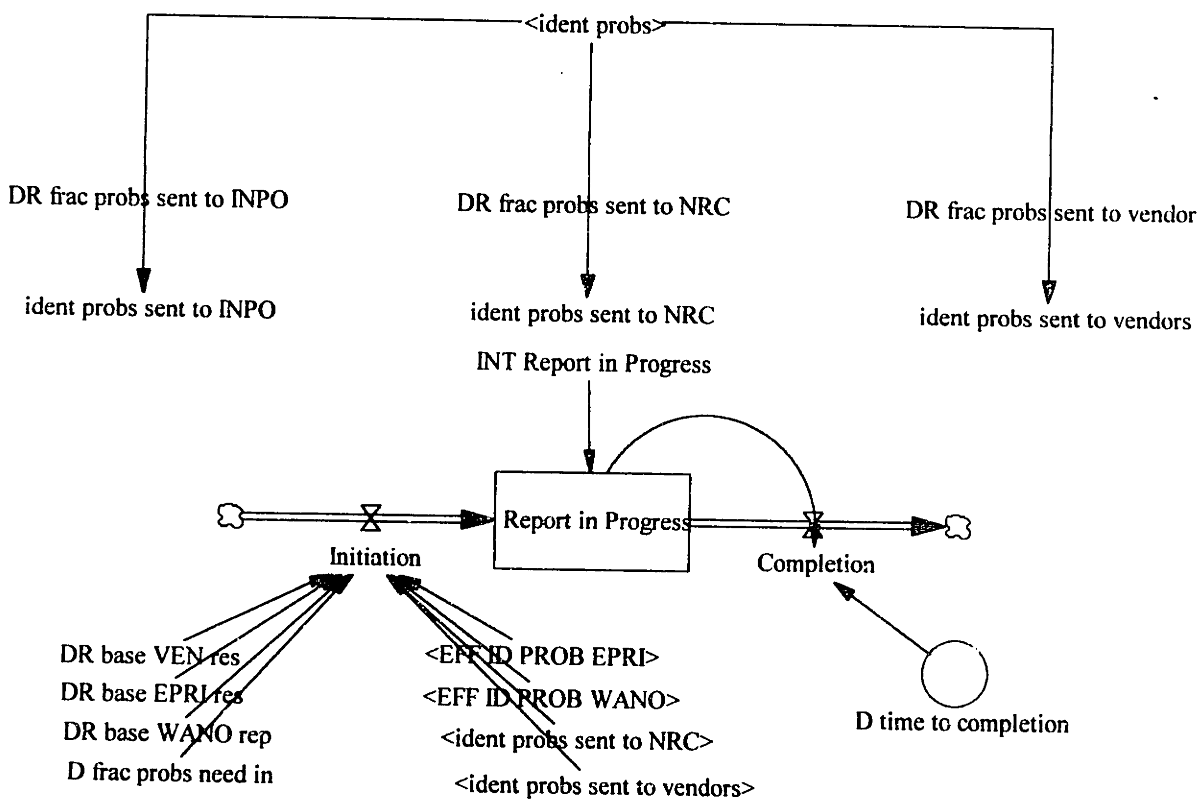
View 41:SALP



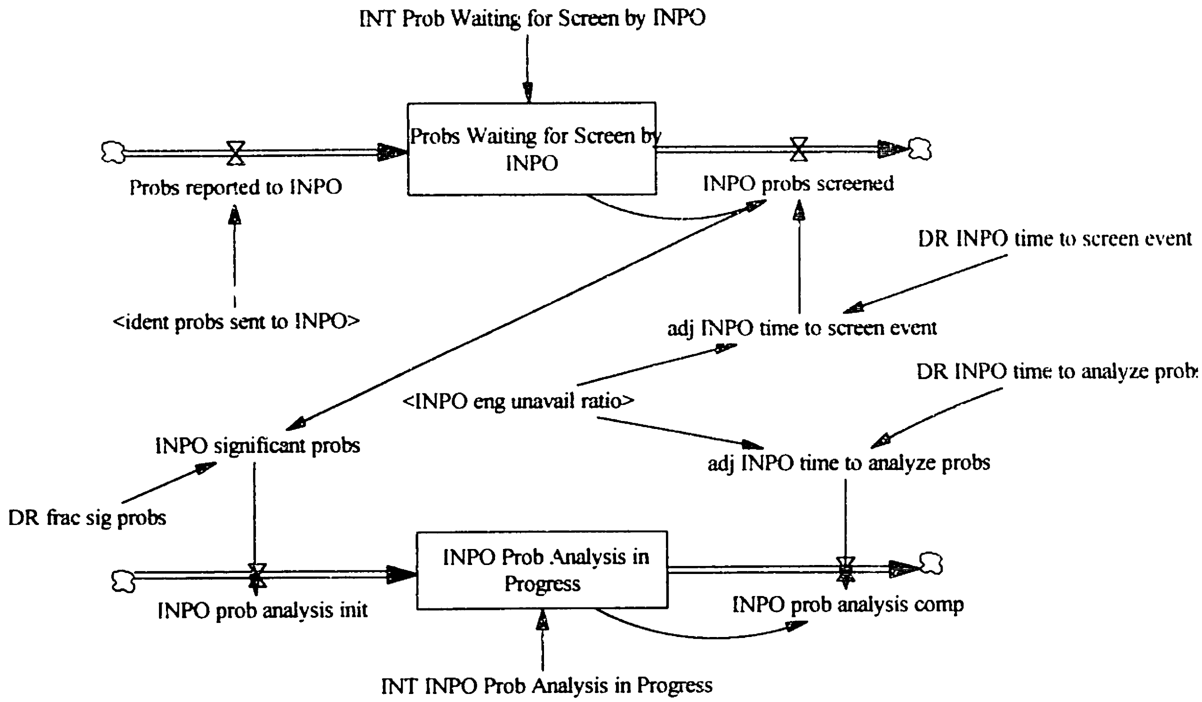
View 42: Event 1



View 43: Event 2



View 44: Problem Reporting



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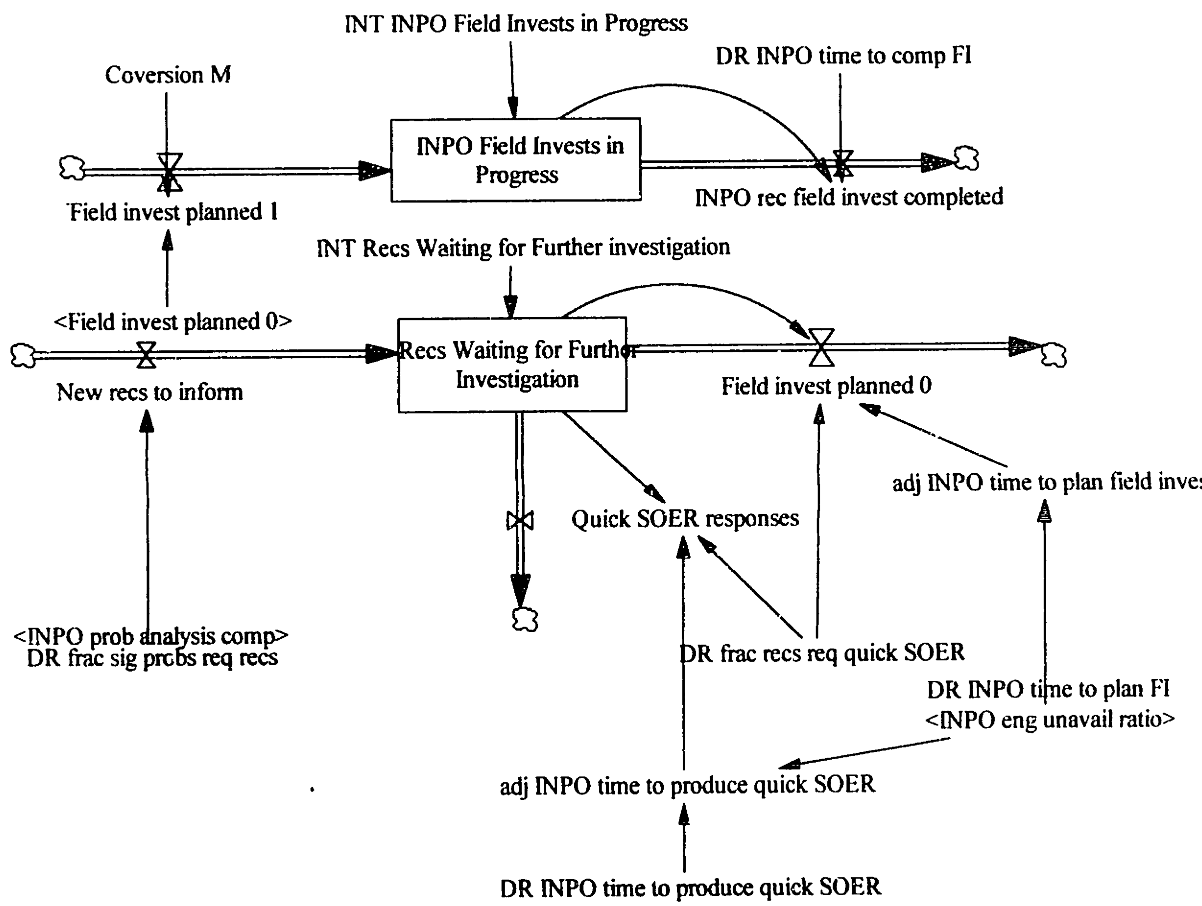
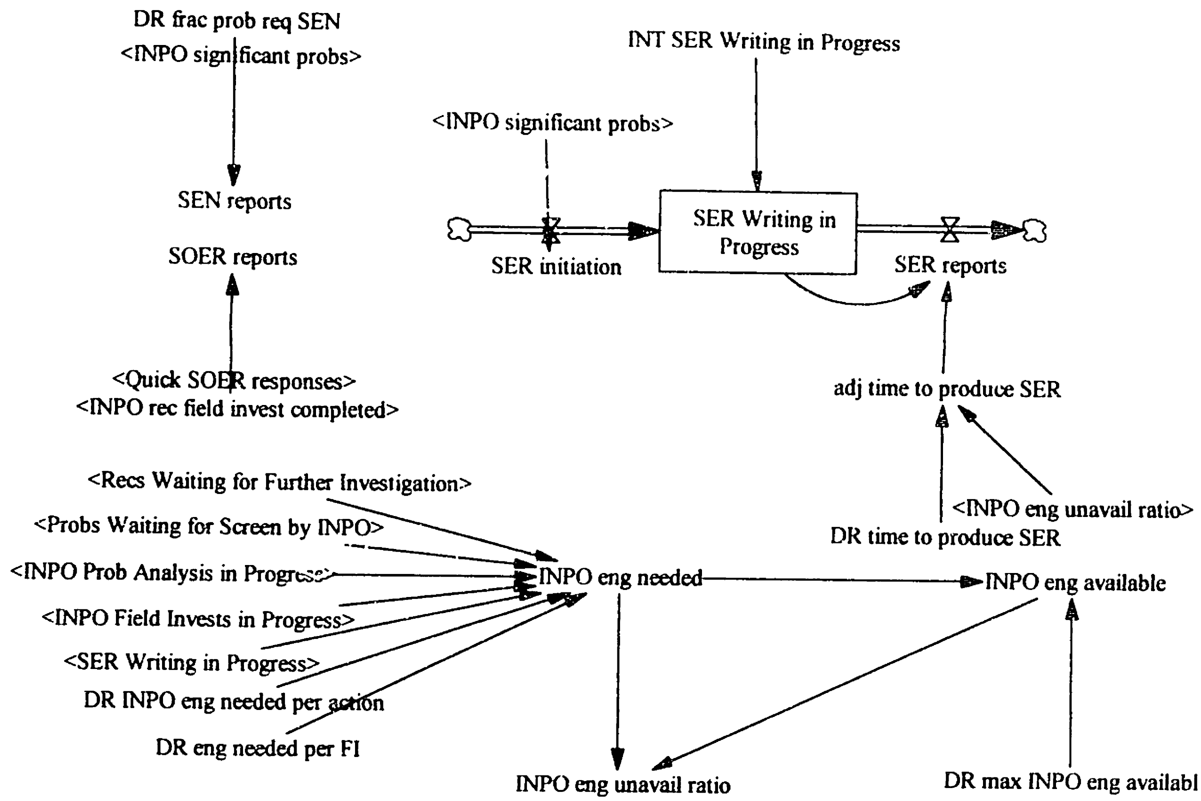
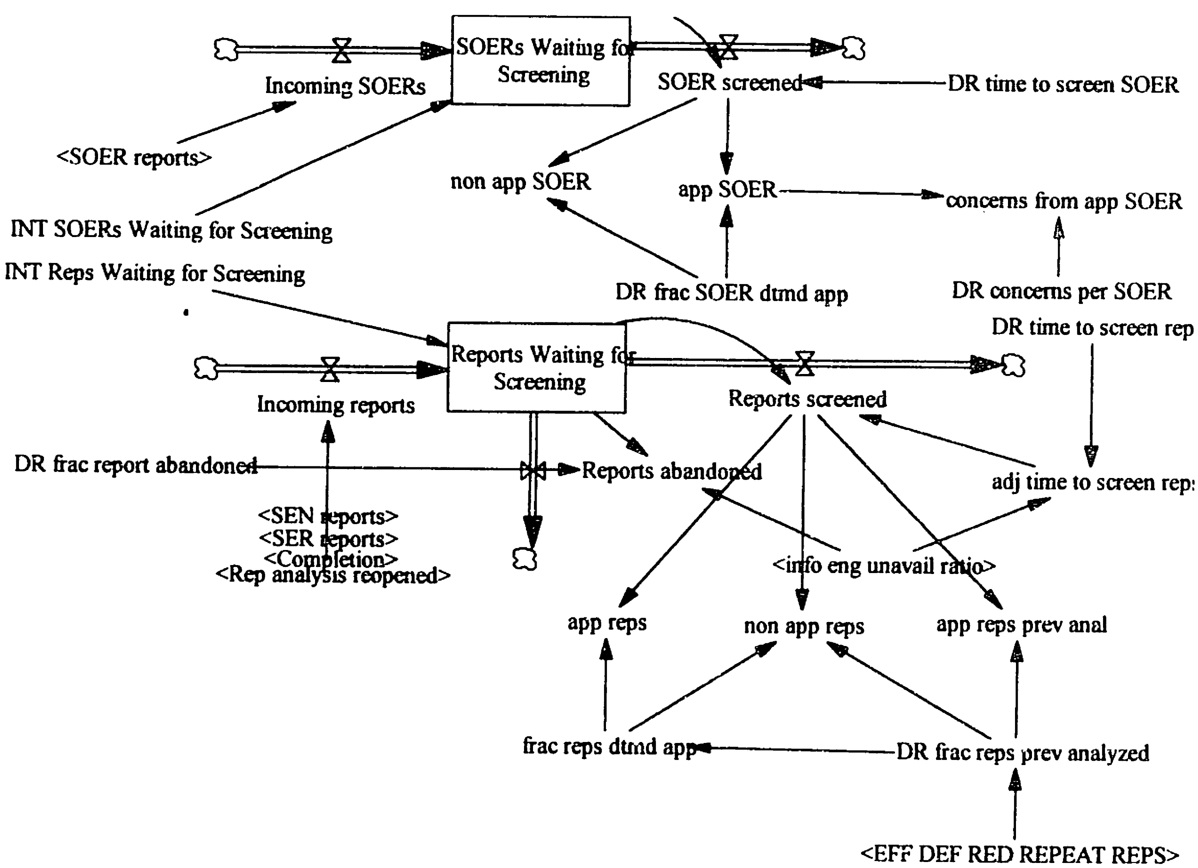


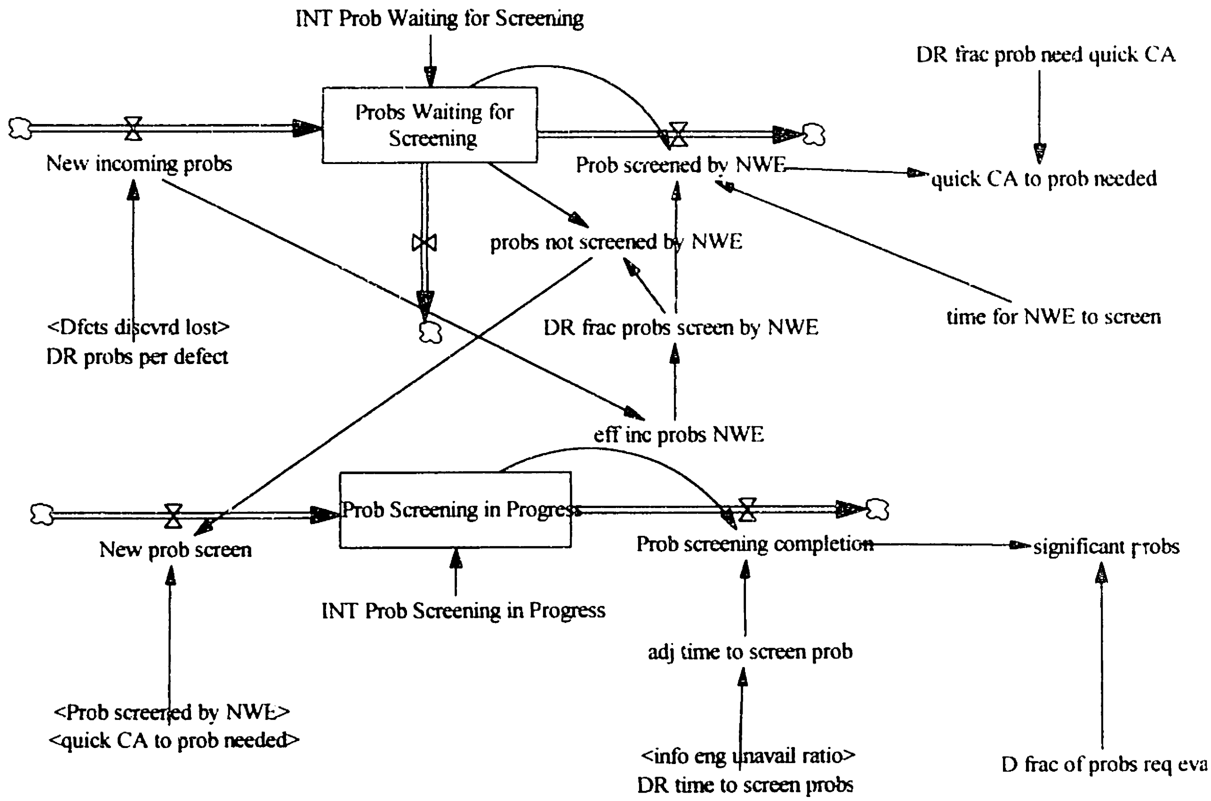
View 46: INPO 2



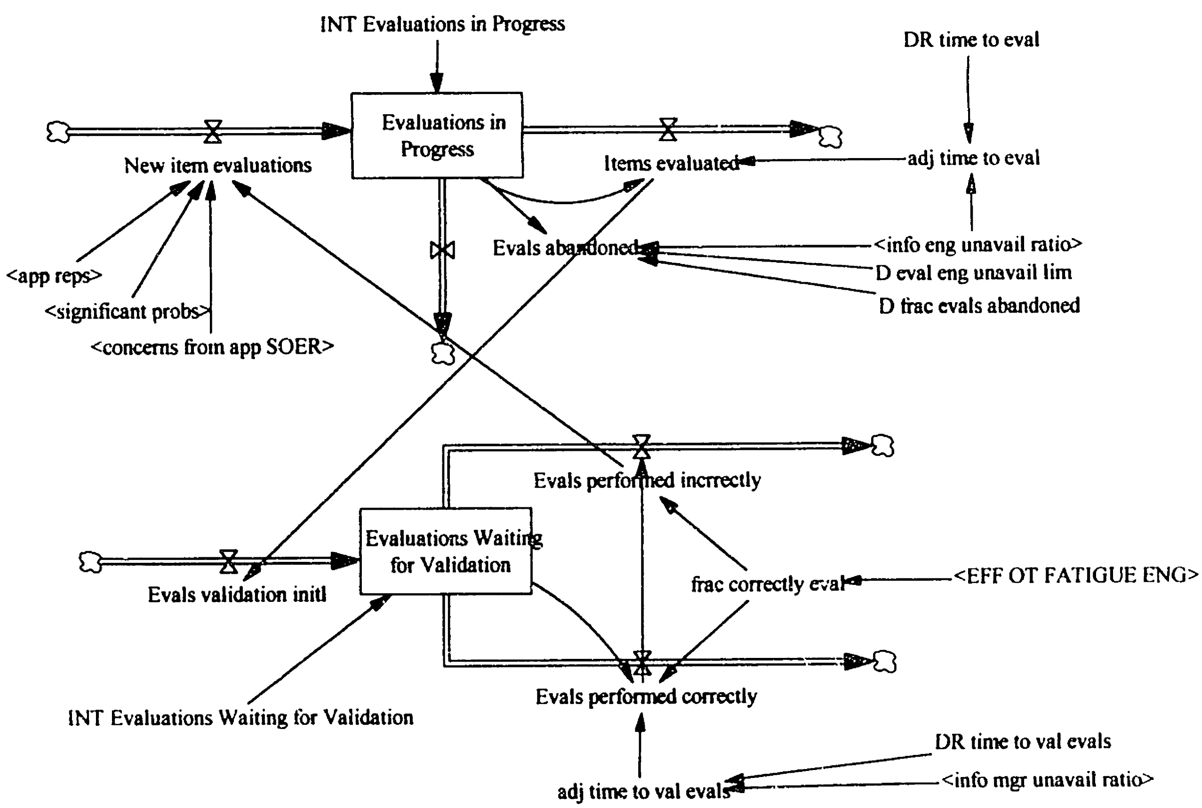
View 47: INPO 3



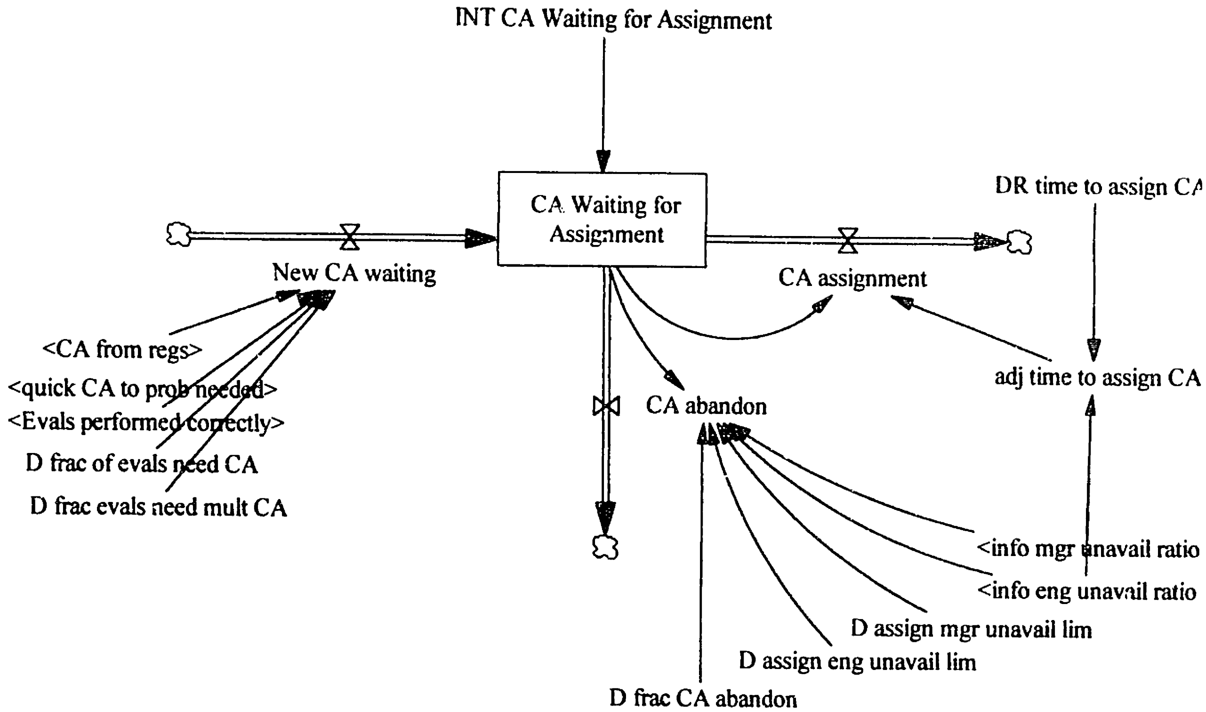
View 48: Report Screening



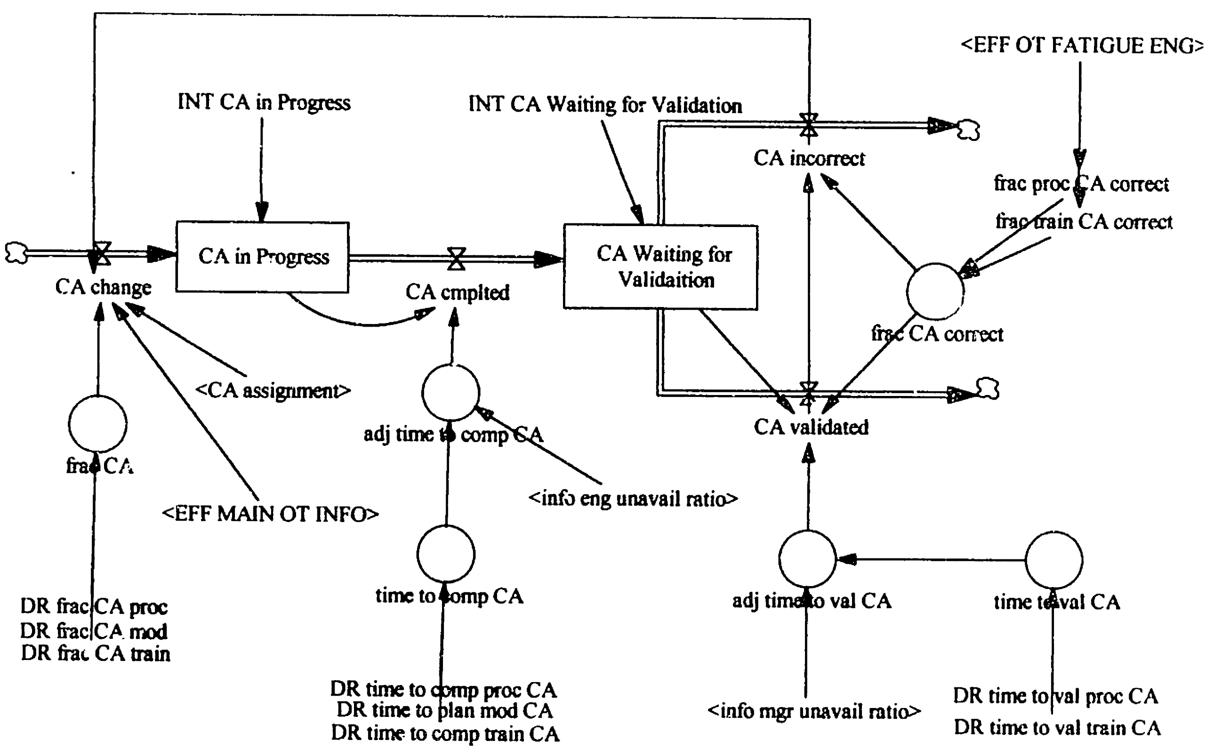
View 49: Problem Screening



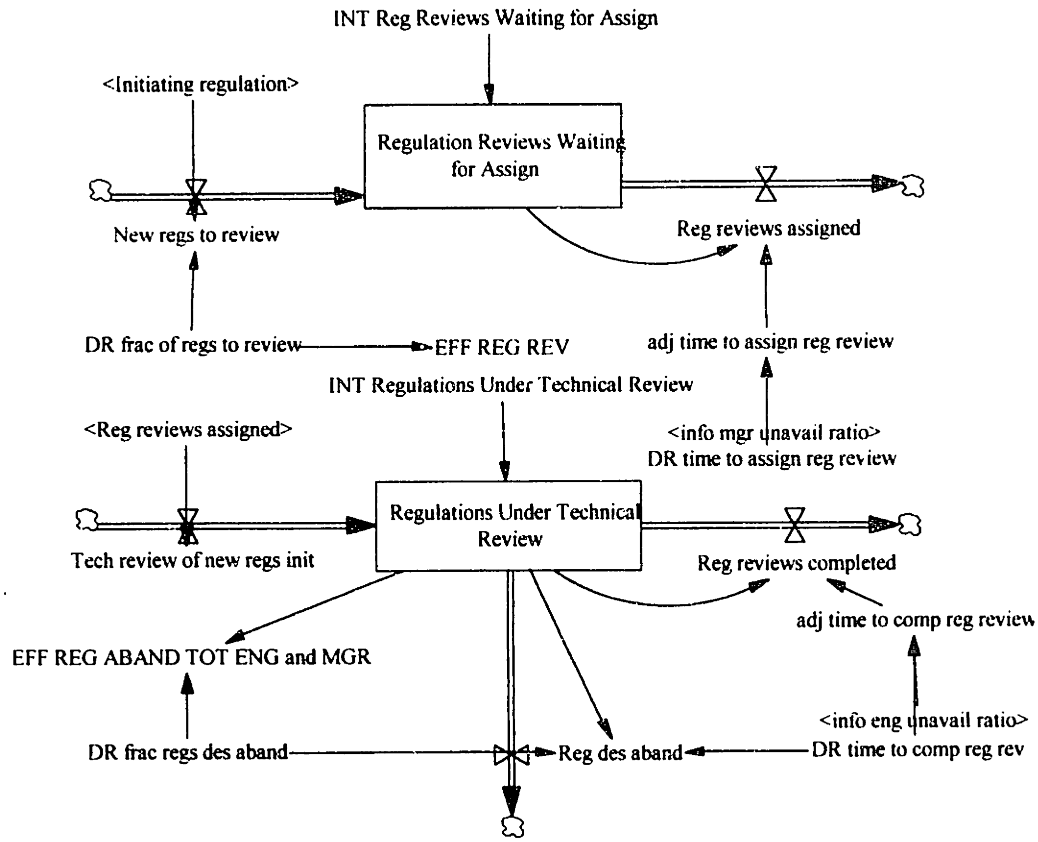
View 50: Evaluation



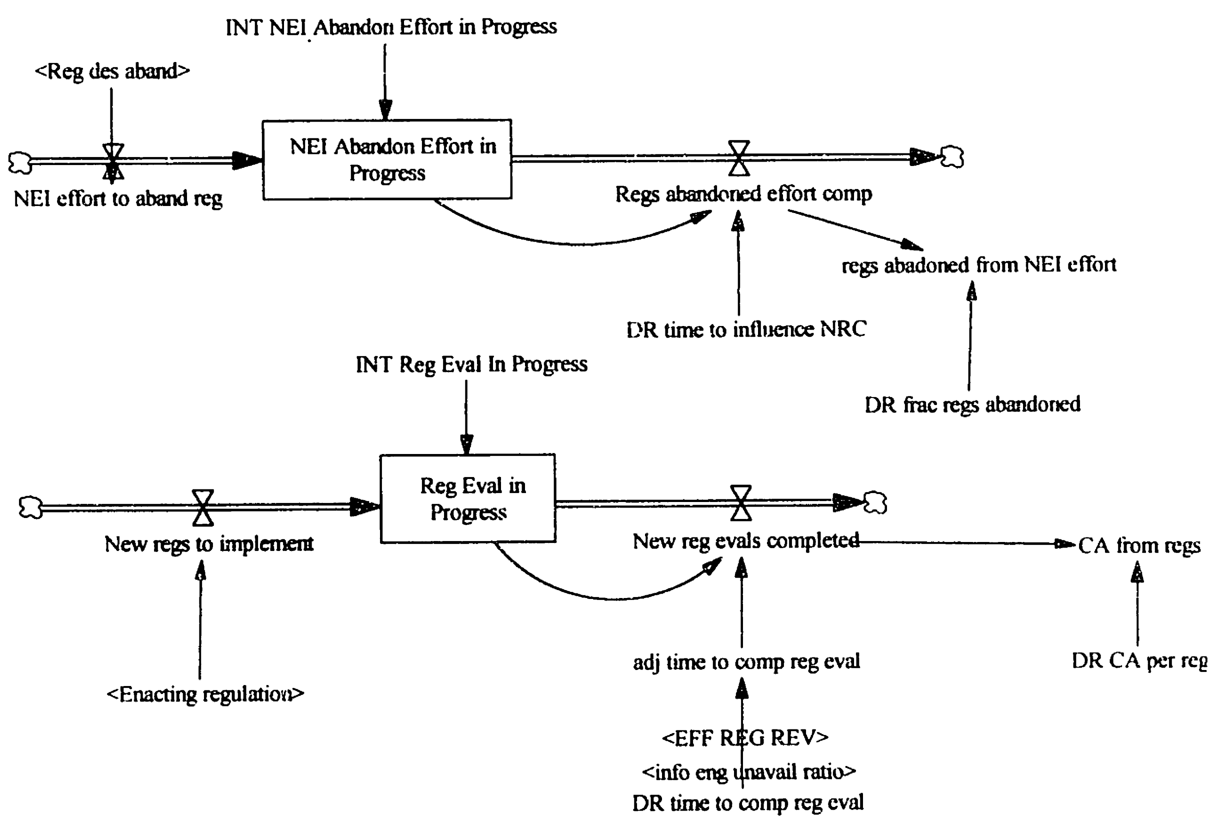
View 51: Corrective Action 1



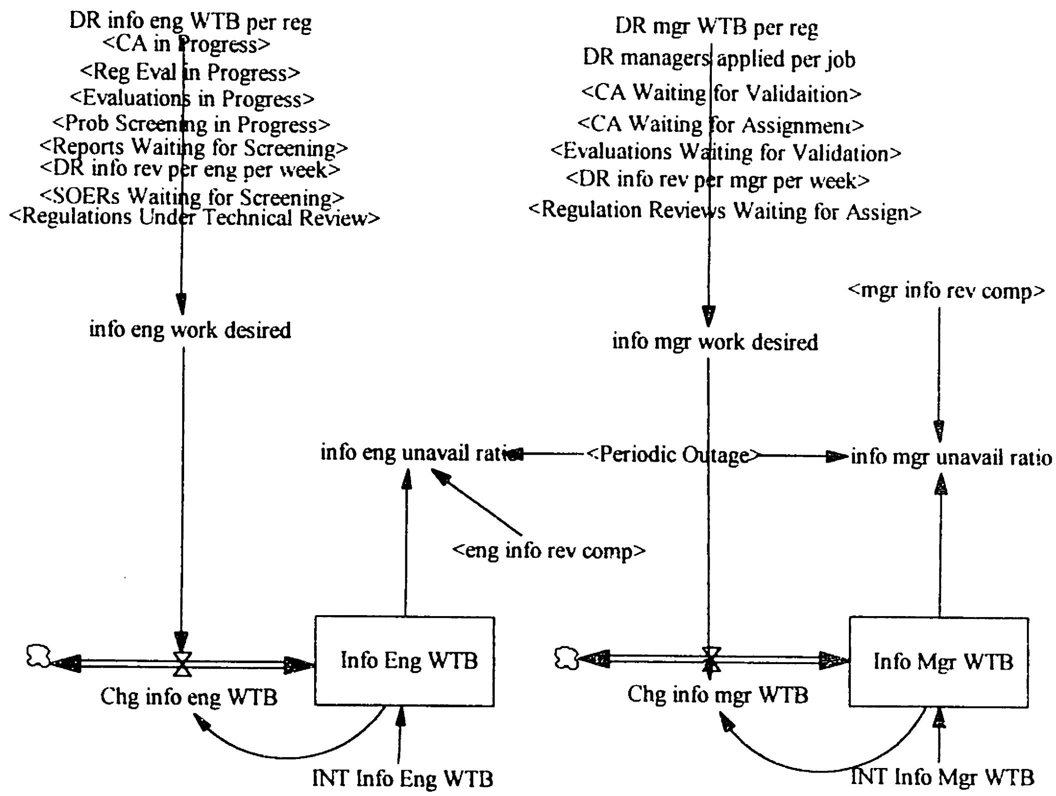
View 52: Corrective Action 2



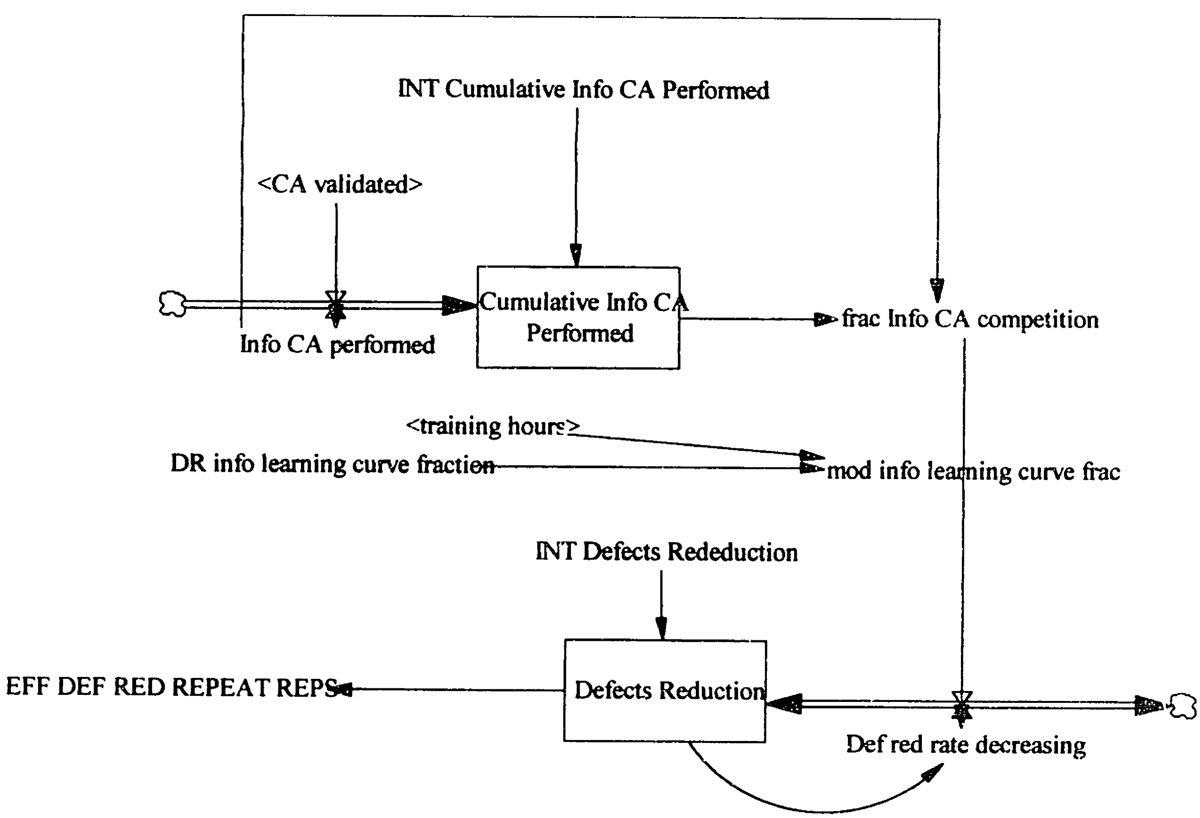
View 53: Interactions with NRC 1



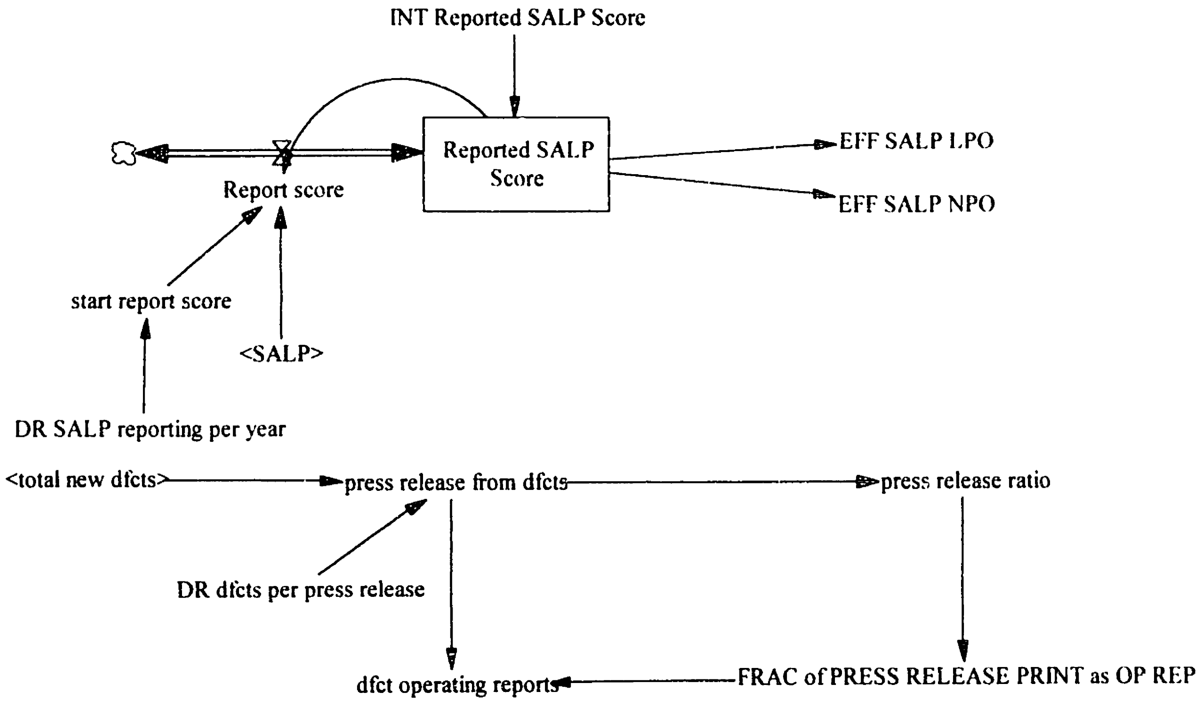
View 54: Interactions with NRC 2



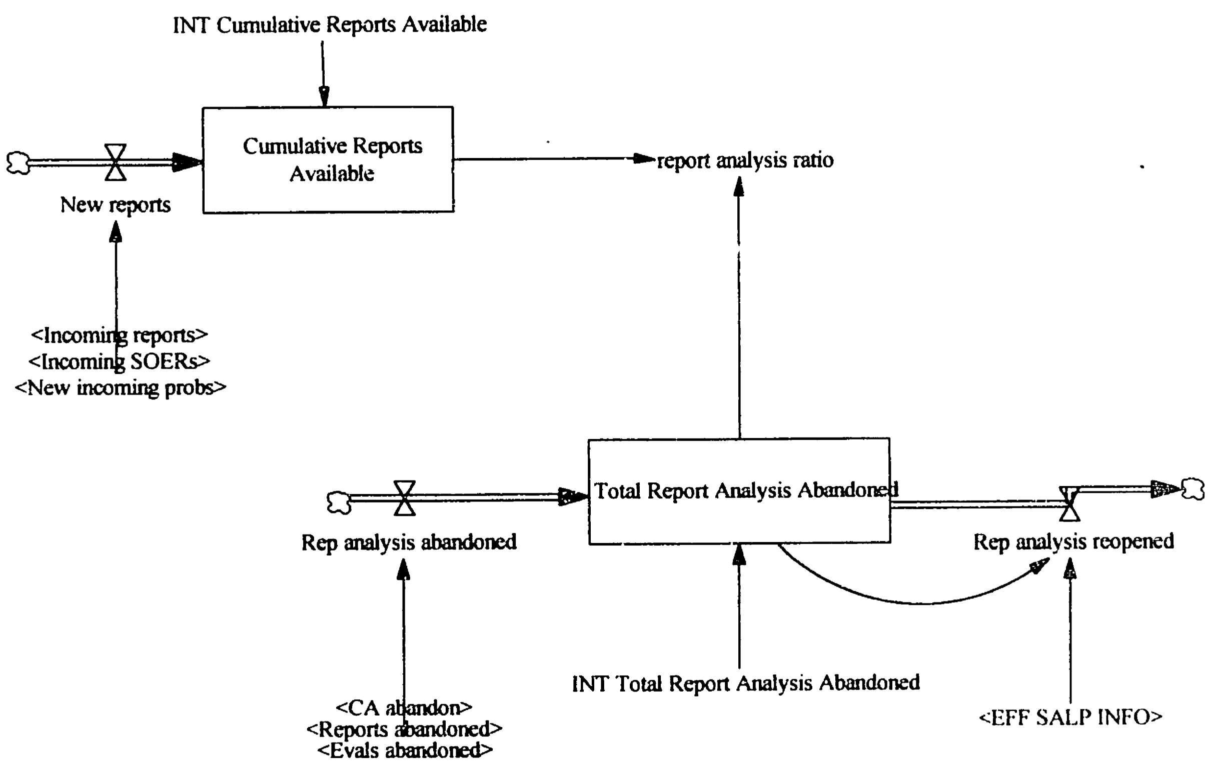
View 55: information Labor



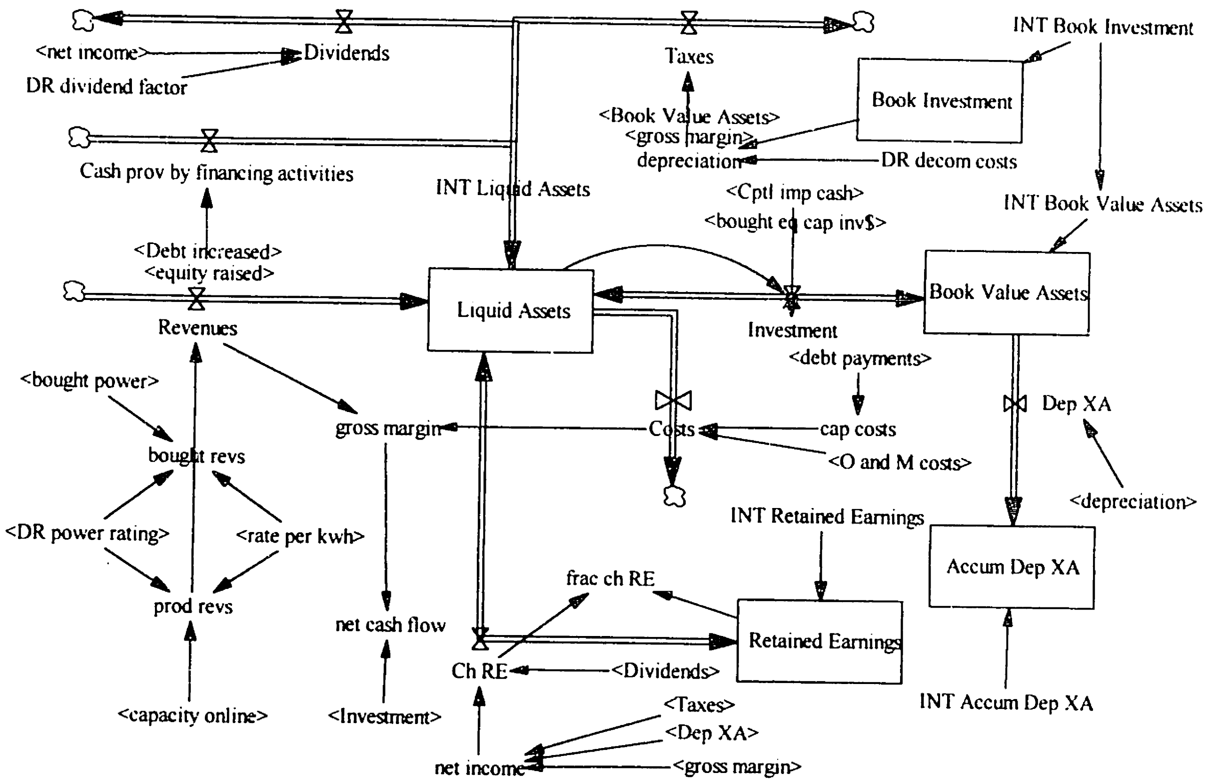
View 56: Information Learning Curve



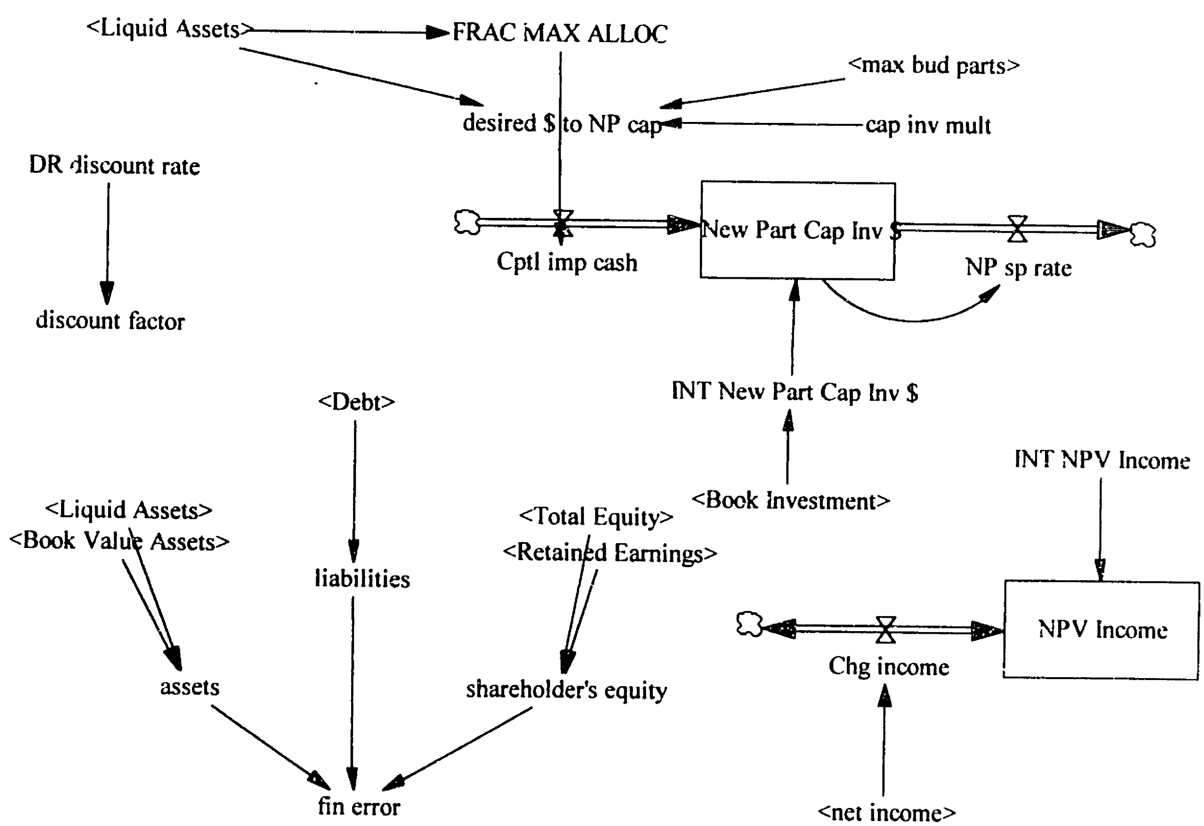
View 57: Public Reporting



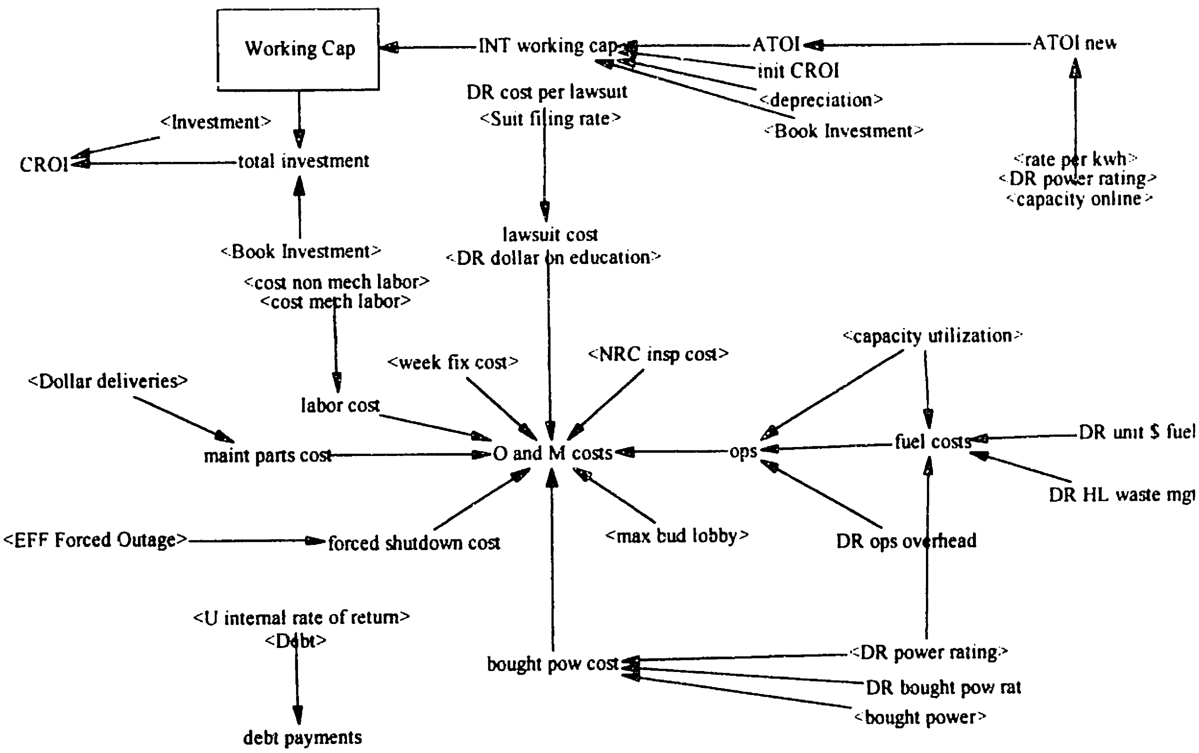
View 58: Information SALP Effect



View 59: Internal Finance 1



View 60: Internal Finance 2



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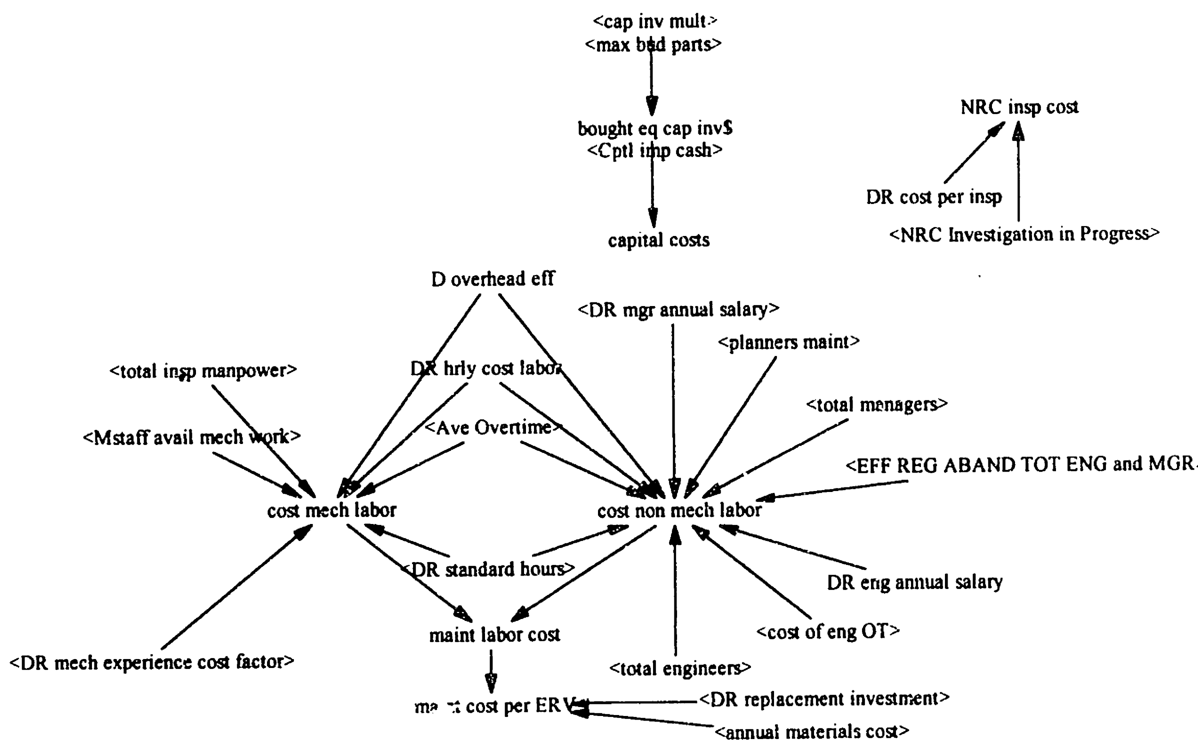
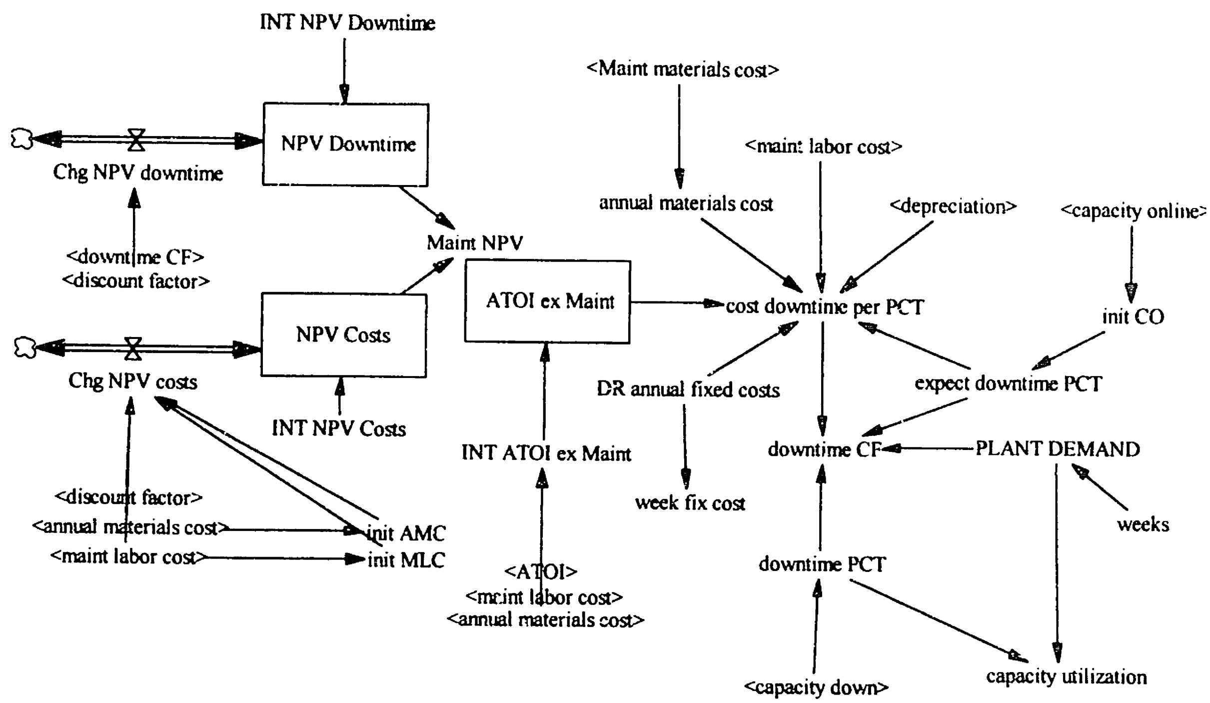
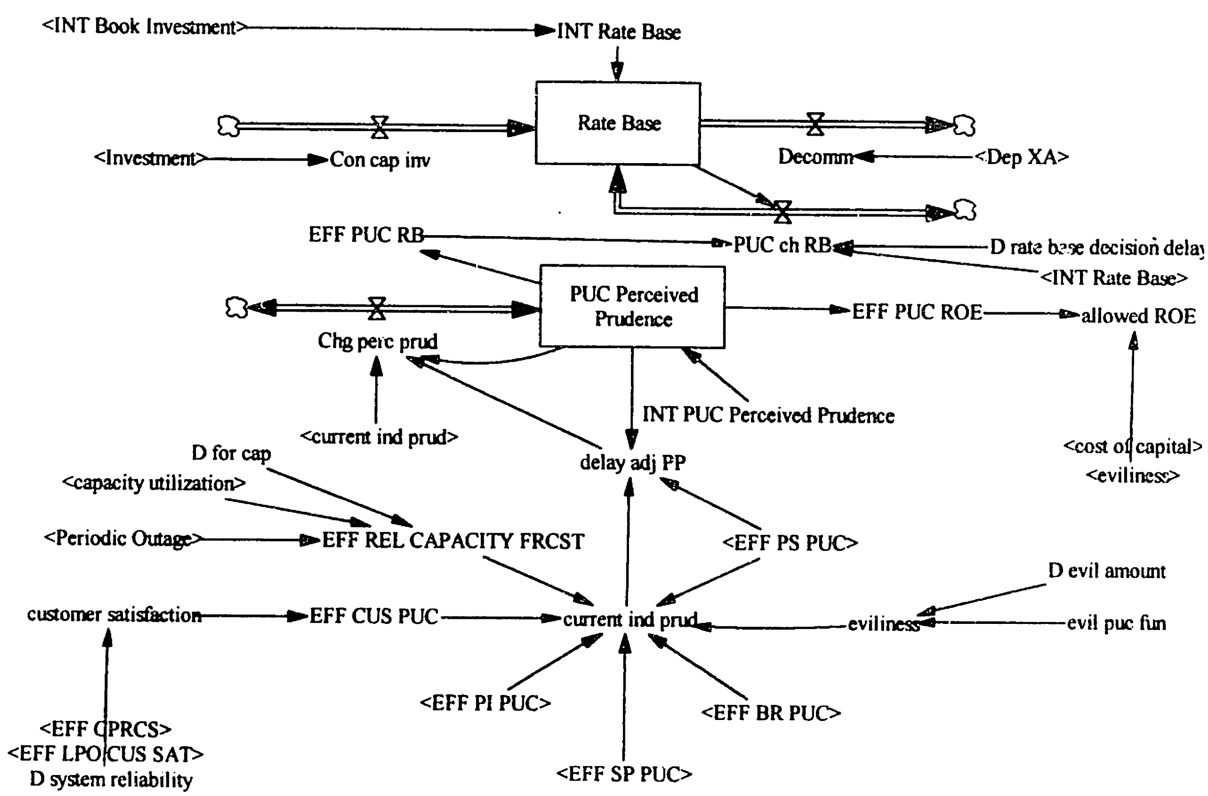


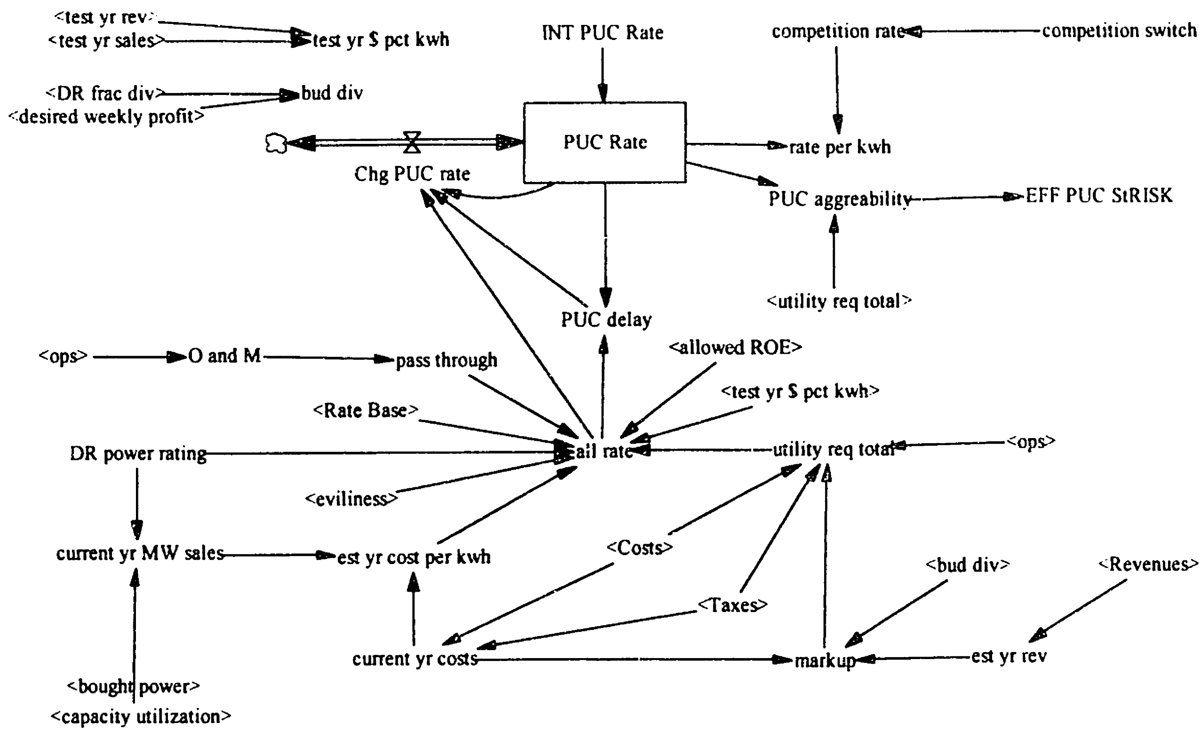
View 62: Internal Finance 4



View 63: Internal Finance 5



View 64: PUC 1



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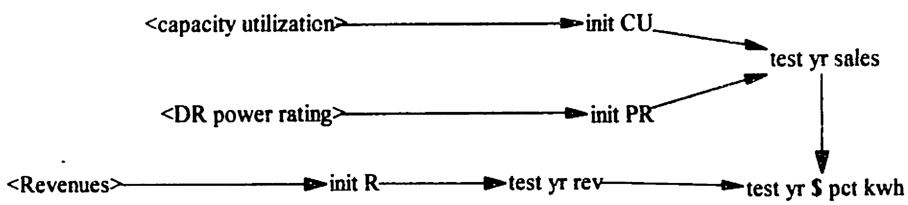
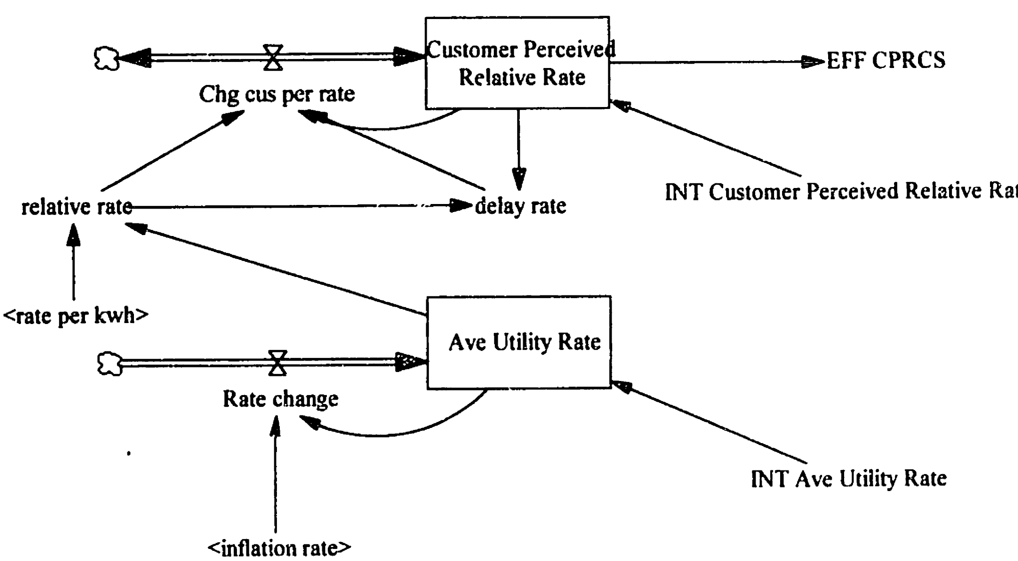
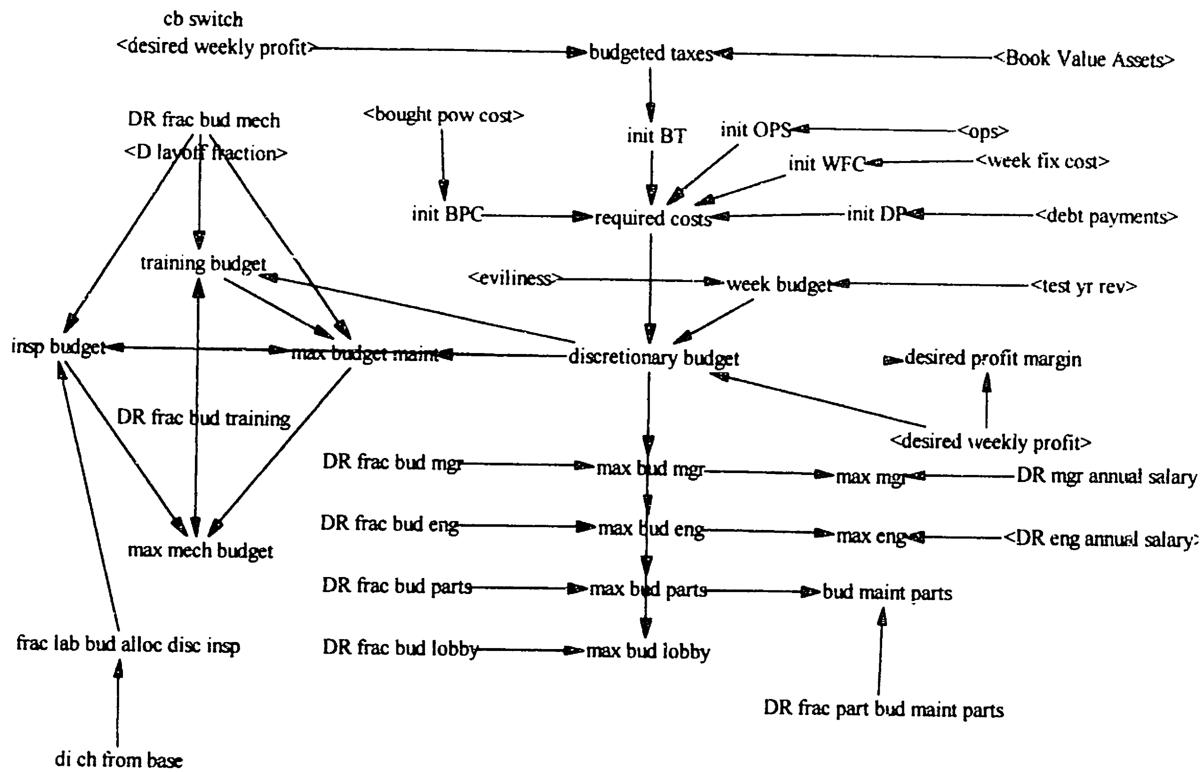
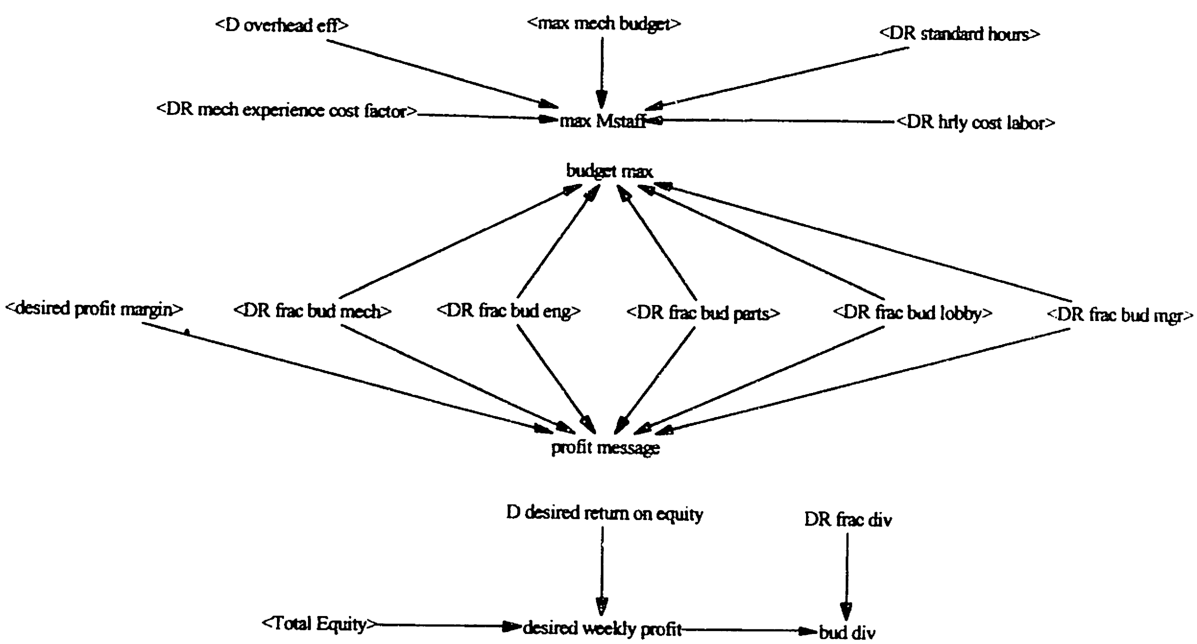




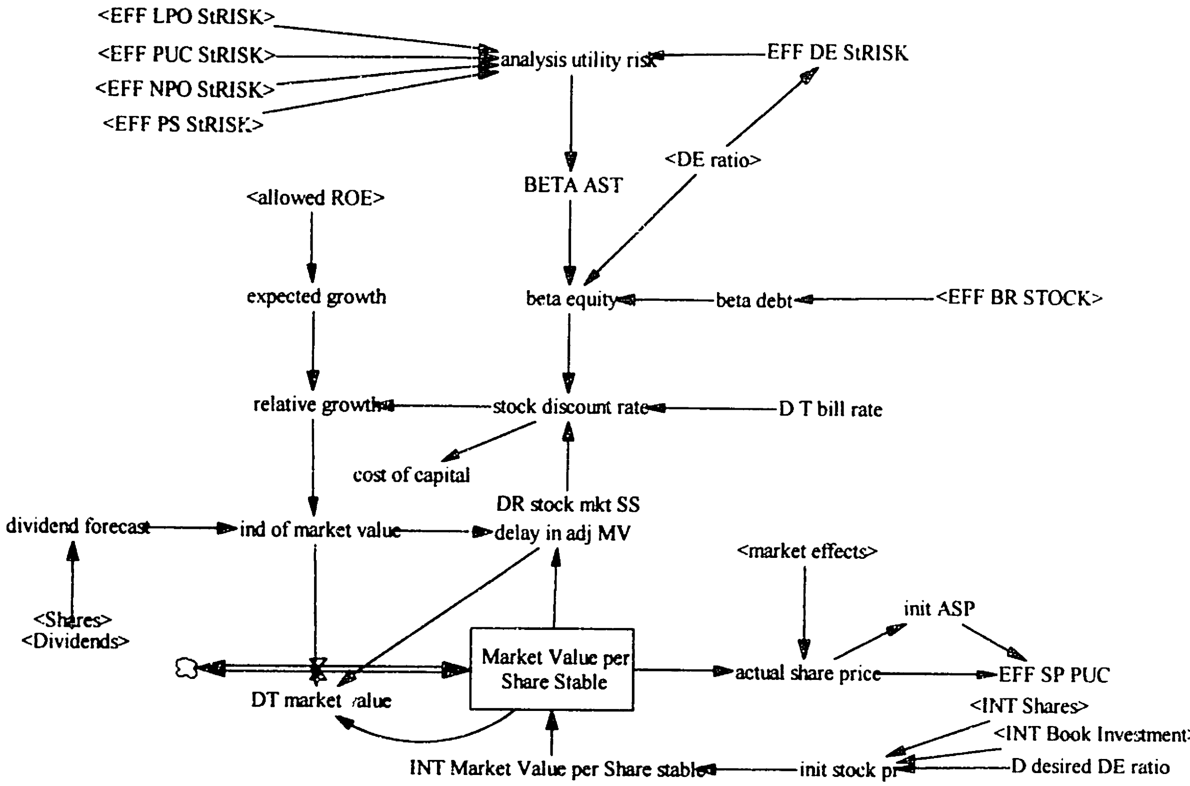
View 66: PUC 3



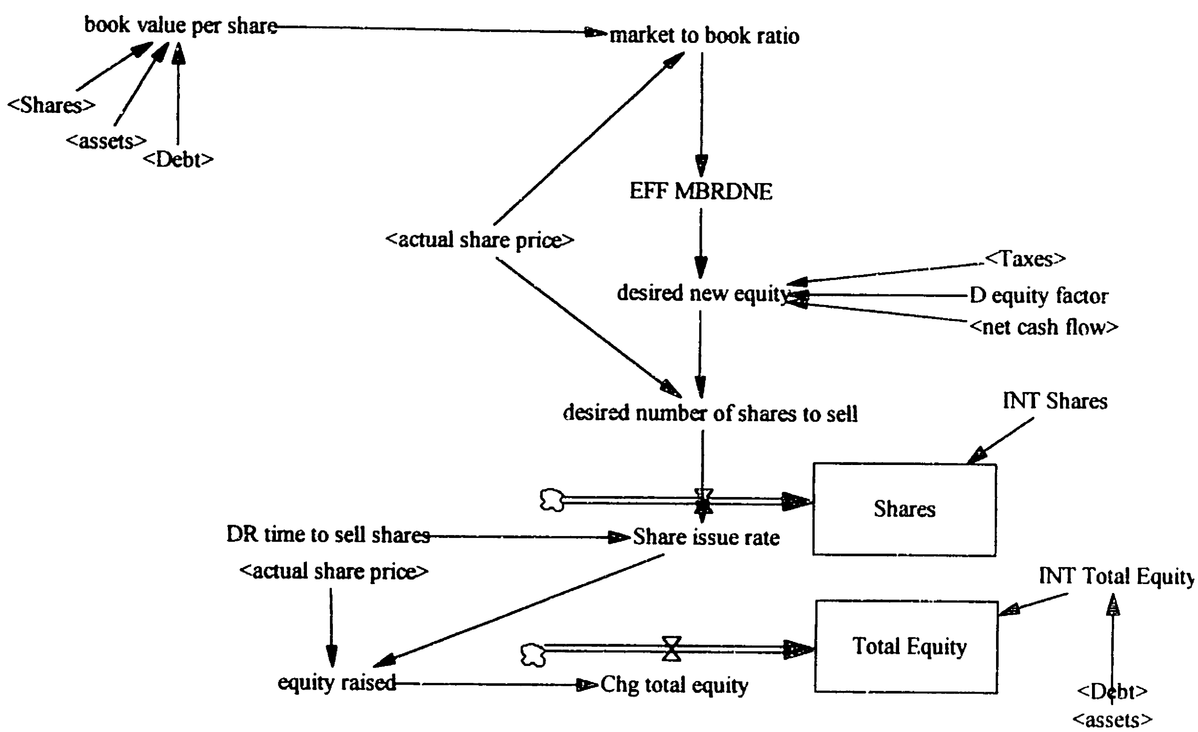
View 67: Budgeting Parameters 1



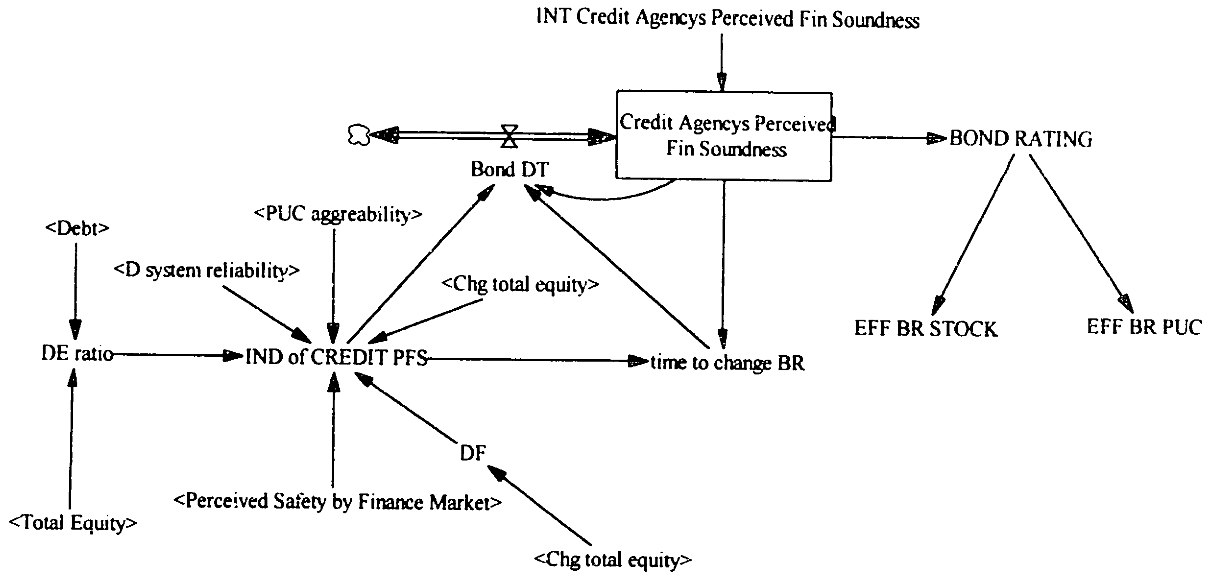
View 68: Budgeting Parameters 2



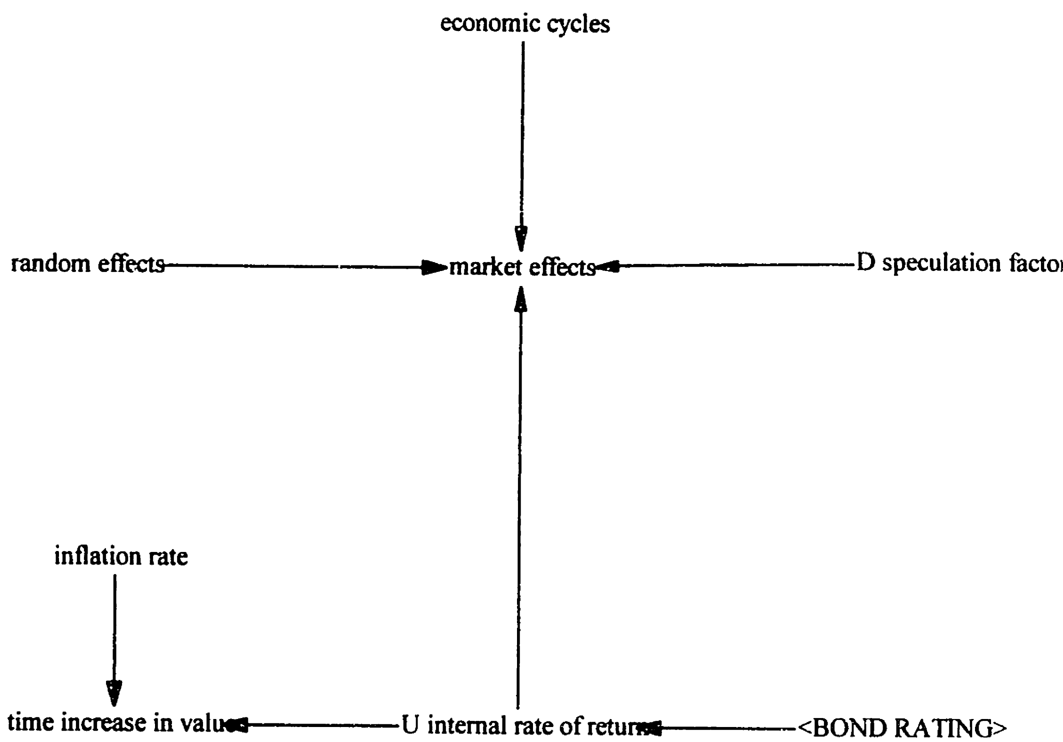
View 69: Stock 1



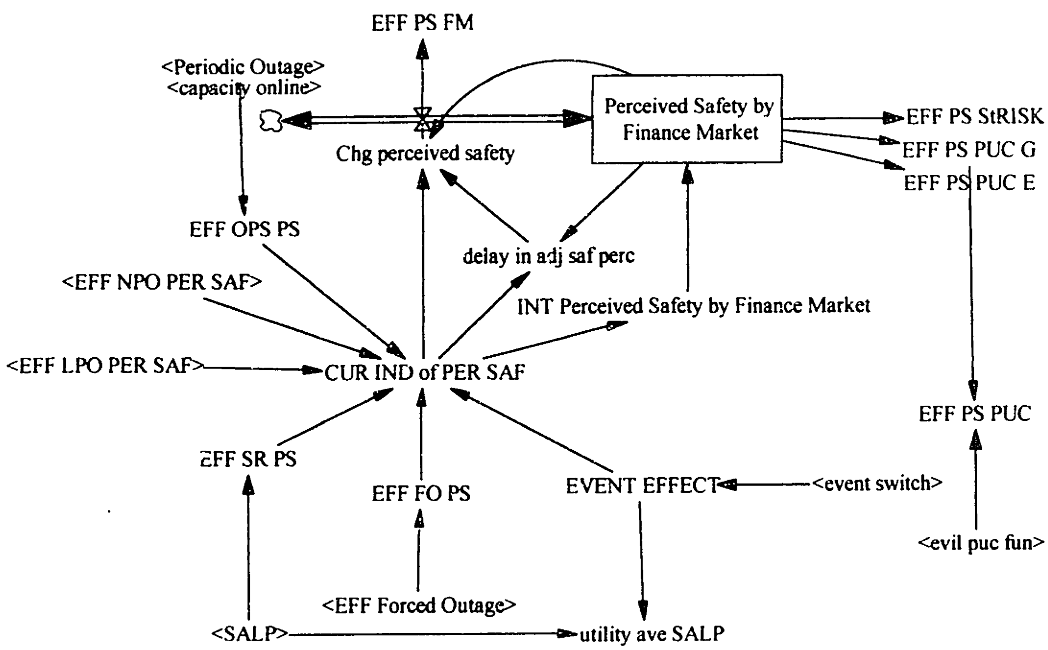
View 70: Stock 2



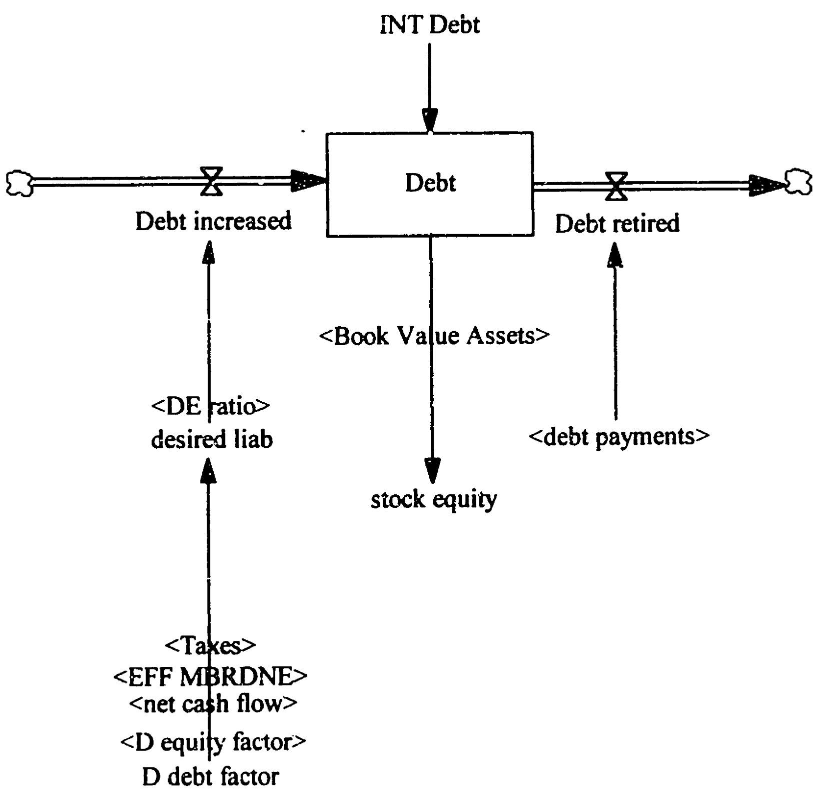
View 71: Bond Rating Institute



View 72: Economics Random Effect



View 73: Financial Safety



View 74: Debt

Appendix B: Model Equations

A. Nuclear Plant Sector (view 1 - 31)

****

A. Capacity Calculation(view 2)

****

frac equip tag PM = Equip Tagged for PM / Total Equipment in Plant

* dimensionless
* Fraction of plant equipment in the preventive or predictive maintenance system.

total equip perceived avail for ops = Equip Perceived Fully Function + Equip Tagged for PM - equip W schd WIP

* Equipment
* Total equipment perceived as either on-line and operating or quickly available for such equipment takedown for PM work but not considered broken.

bought power = IF THEN ELSE((DR customer demand-capacity on-line)<0,0,(DR customer demand-capacity on-line))

* percentage
* This is the power that must be bought by the utility to make up for power not generated.

capacity bdwn = frac equip bdwn

* dimensionless
* Capacity down due to equipment breakdown. Assume S shaped curve due to on-line spares for common breakdowns but no spares for infrequent breakdown items. This data should be gotten from a sage model analysis of the facilities involved. The current curve is assumed to be the same as for takedowns. However if the plant has a breakdown, forced outage due to a scram there is a time delay until the cause is found and corrected and the plant can be legally started up. During this time the capacity is zero.

capacity down = MIN(((capacity bdwn+capacity tdwn)*100), 100)

* percentage
* Total capacity down from both breakdowns and takedowns.

capacity on-line = MAX((1-capacity bdwn-capacity tdwn)*100, 0) * (1-Periodic Outage)

* percentage
* Capacity on-line

capacity tdwn = F capacity tdwn(frac equip tdwn)

* dimensionless
* Capacity down due to equipment takedown. Assume S-shaped curve due to the intelligence of people to take things down that have the least effect on capacity. This data should be gotten from a sage model analysis of the facilities involved. The current curve is assumed to be the same as for breakdowns.

DR customer demand = 80

* percentage
* Customer demand.

equip W schd WIP = Schd Work Order[S5] * DR equip per WO

* Equipment
* Equipment with scheduled work in progress.

frac equip bdwn = Equip Brokendown / Total Equipment in Plant
* dimensionless
* Fraction equipment brokendown. Fraction of equipment that is broken down.

frac equip tdwn = (equip W schd WIP / Total Equipment in Plant) + EFF Forced Outage
* dimensionless
* Fraction of equipment that has been removed from service due to scheduled maintenance.

production pressure = IF THEN ELSE((Periodic Outage=0),(PLANT DEMAND / (capacity online*0.89+10)),0)
* dimensionless
* Production pressure.

****
A. Defects flows 1(view 3)
****

maintd equip PM = DR equip per WO * Completed schd WO[S5]
* Equipment/week
* Equipment that has been maintained through the preventative maintenance system thereby eliminating the defect or postponing breakdown (extending life).

New dfcts un ID = (new dfcts ops+new dfcts bdwn)
*(1-frac equip tag PM)+(new dfcts from wmanship+New dfcts parts) * defects/week
* New unidentified defects in equipment. Defects can occur in all equipment. However, defects from wear or cascading defects resulting upon breakdown of other equipment are assumed to occur only in equipment not in the PM program; iE. the PM program is designed to eliminate breakdowns due to wear and tear.

Defects ID = SINTEG(Dfcts discvrd lost+New dfct PM equip-Dfcts fixed because PM equip bdwn
-Dfcts fixed schd WO, INT Defects ID,0,:NA:,:NA:,:NA:,:NA:)
* defects
* Defects that have been identified through inspections or suspected by information gained from historical data. Defects included in this category would either be from equipment within the PM system or other equipment which foe some reason was inspected. One assumption of this model is that the plant will have a general understanding of the status of equipment within the plant PM system, more knowledge than for equipment outside of the PM program. Equipment may still function with a defect. However, a defect implies that the equipment may not perform as designed and hence have a higher probability of failure.

Defects Un ID = SINTEG(+New dfcts un ID-Dfcts fixed because equip bdwn
-Dfcts discvrd lost, INT Defects Un ID,0,:NA:,:NA:,:NA:,:NA:)
* defects
* Defects in plant equipment that have gone unidentified. Equipment may still function with a defect. However, defects significantly increase the probability of equipment failure or the inability of equipment to fully function under design conditions.

Dfcts fixed because equip bdwn = on-line bdwns * dfcts per dfct equip PFF
* defects/week
* Unidentified defects are eliminated, identified and subsequently repaired, as a result of equipment failure.

Dfcts discvrd lost = IF THEN ELSE(Time>52,dfct ID from insp-dfcts forgotten,900)
* defects/week
* The positive flow is defects identified by inspections. The negative flow are defects that are forgotten about because of inadequate record keeping and information systems.

Dfcts fixed because PM equip bdwn = tagged PM equip bdwns*dfcts per dfct equip PM
* defects/week
* Some identified defects are eliminated because the equipment breaks down and is consequently repaired.

Dfcts fixed schd WO = IF THEN ELSE(Time>52,maintd equip PM*FRAC EQUIP PM DFCT
*dfcts per dfct equip PM,950)
* defects/week
* Defects eliminated by the completion of unscheduled work.

dfcts forgotten = schd WO aw eq forgotten*DR equip per WO*FRAC EQUIP PM DFCT
*dfcts per dfct equip PM
* defects/week
* Some work orders may be forgotten, lost,misplaced or simply discarded. Each of those forgotten WO represents a number of defects which then go from being identified to being unidentified.

frac dfcts un ID = Defects Un ID / (total defects+100)
* dimensionless
* The fraction of total defects which go undetected.
*:SUPPLEMENTARY

INT Defects ID = 619.51*5
* defects
* Initial defects identified.

INT Defects Un ID = 62000
* defects
* Initial defects identified.

New dfct PM equip = (new dfcts ops+new dfcts bdwn)*frac equip tag PM
* defects/week
* Defects or potential defects in equipment within the PM system, the existence of which the plant becomes aware or suspects.

total defects = Defects ID + Defects Un ID
* defects
* The total number of defects in plant equipment, both identified and unidentified.

****

A. Defects flows 2(view 4)

****

total new dfcts = new dfcts ops+new dfcts bdwn+new dfcts from wmanship+New dfcts parts
* defects
* The total number of new defects

share new dfcts stores = ZIDZ(New dfcts parts, total new dfcts)
* dimensionless
* Share of new defects from stores and parts problems.
*:SUPPLEMENTARY

dfct equip PFF = Equip Perceived Fully Function * FRAC EQUIP PFF DFCT
* defective equipment
* The equipment that is perceived as fully functional but in fact is defective.

dfct equip PM sys = Equip Tagged for PM*FRAC EQUIP PM DFCT
* pieces of equipment
* Equipment in preventative maintenance system that is defective.

dfcts per dfct equip PFF = ZIDZ(Defects Un ID, dfct equip PFF)
* defects/Equipment
* The number of defects per unit of defective equipment that is in the predictive and preventive system.

dfcts per dfct equip PM = Defects ID / (dfct equip PM sys+10)
* defects/Equipment
* The number of defects per unit of defective equipment that is in the predictive and preventive system.

dfcts per equip PFF = ZIDZ(Defects Un ID , Equip Perceived Fully Function)
* defects/Equipment
* Calculates the number of defects per piece of equipment PFF.

dfcts per equip PM sys = Defects ID / (Equip Tagged for PM+100)
* defects/Equipment
* The number of defects per piece of equipment in preventative maintenance system.

EFF DEF ID BDWN = F EFFDefldbrkdn(Equip Tagged for PM/(Equip Perceived Fully Function+100))
* dimensionless

DR frac dfct bdwn = 1/12
* equip breakdowns/defect/week
* Fraction of defects that cause breakdowns per week. (All defects will cause breakdowns in 12 weeks if this fraction is 1/12)

FRAC EQUIP PFF DFCT =F frac equip pff dfct(dfcts per equip PFF)
* defective equipment/Equipment
* There may be more than one defect per piece of equipment. This function graphically relates the total unidentified defects/equipment perceived fully functional to the fraction of pieces of equipment with defects.

FRAC EQUIP PM DFCT =F frac equip PM dfct(dfcts per equip PM sys)
* defective equipment/PM equipment
* There may be more than one defect per piece of equipment. This function graphically relates defects/equip within the PM system to the fraction of pieces of equipment with defects.

on-line bdwns = Defects Un ID * DR frac dfct bdwn
* equipment breakdowns/week
* Breakdown of equipment that is on-line.

share new dfcts bdwn = ZIDZ(new dfcts bdwn , total new dfcts)
* dimensionless
* Share of new defects from breakdowns.
*:SUPPLEMENTARY

share new dfcts ops = ZIDZ(new dfcts ops, total new dfcts)
* dimensionless
* Share of new defects from operations.
*:SUPPLEMENTARY

share new dfcts wmanship = ZIDZ(new dfcts from wmanship, total new dfcts)
* dimensionless
* Share of new defects from poor workmanship.
*:SUPPLEMENTARY

tagged PM equip bdwns = Defects ID * DR frac dfct bdwn * EFF DEF ID BDWN
* Equipment/week
* The breakdown of equipment that is in the planning and predictive system and currently under inspection or being maintained.

****

A. Defects sources(view 5)

****

new dfcts from wmanship = IF THEN ELSE(Time>25,(total maintd equip * Event Occurance Rate[WO] * smth EFF OT DG * defect reduction* EFF ENG WO RT DEF* EFF UW ERT DEF * EFF UWO MRT DEF * EFF MT WO RT DEF), 1500)
* defects/week
* New defects introduced from poor workmanship.

new dfcts ops = IF THEN ELSE(Time > 52, (total equip perceived avail for ops * defect reduction * Event Occurance Rate[BE] * (1-frac new equipment)), 4800)
* defects/week
* New defects resulting from simply operating plant equipment.

DR base dfcts ops per week = 0.115 * (1-frac new equipment)
* defects/Equipment/week
* Base level of defects which result from wear and tear of normal operations.

DR base dfcts from wmanship = 0.35
* defects/Equipment
* Base defect from workmanship. Base level of defects resulting from worker error or mishap. Base value does not account for effects of experience or training. It will now-MGT8/4/94.

DR base dfcts per bdwn = 0.45
* defects/breakdown
* Base level of defects per breakdown of another or the same piece of equipment. Not influenced by experience or improvement of plant system and procedures.

defect reduction = Defects Reduction
* dimensionless
* Test parameter to reduce defects by arbitrary percentage. If it is 0.7, defects are reduced by 30%.

frac new equipment = New Equipment / Total Equipment in Plant
* dimensionless
* Fraction of new equipment to total equipment in plant.

new dfcts per bdwn = DR base dfcts per bdwn*defect reduction
* defects/breakdown
* New defects resulting from a breakdown of another or same piece of plant equipment.

new dfcts bdwn = IF THEN ELSE(Time>52,(total bdwns*new dfcts per bdwn),2200)
* defects/week
* New defects caused by the breakdown of other or same piece of plant equipment.

smth EFF OT DG = SMOOTHI(EFF OT DG, 6, 1)

total bdwns = on-line bdwns + tagged PM equip bdwns
* equipment breakdowns/week
* Total breakdowns of all plant equipment, both equipment on-line and operating and equipment off-line under inspection or maintenance.

total maintd equip = total WO completed * DR equip per WO
* Equipment/week
* All equipment worked on as a result of a scheduled or unscheduled work orders.

****
A. Engineer 1(view 24)
****

Engineer hiring = DR eng attrition + (NEW ENG HIRING from OT
* new hiring switch eng / D eng hiring delay) + Promotions
* people/week
* The hiring of new mechanics.

engineer layoffs = IF THEN ELSE(Time=100, D eng layoff fraction * total engineers
* D time to layoff engs / TIME STEP, ENG LAYOFFS from OT * people
* Maintenance layoffs. This is a policy variable that is an exogenous function of time.

Pro engineer loss = engineer layoffs / D time to layoff engs + DR eng attrition
+ bud layoff eng / D time to layoff engs
* people/week
* Engineering staff loss.

INT Pro Engineers = 0.4 * INT Maintenance Staff
* people
* The initial value of pro engineering staff.

INT Rookie Engineers = 5
* people
* The initial value of rookie engineering staff.

bud layoff eng = IF THEN ELSE(total engineers>max eng, (total engineers - max eng), 0)
* people

EFF ESTAFF EXP =F EFF Estaff exp(eng exp ratio)
* dimensionless

DR eng attrition = 0.001 * Pro Engineers
* people/week
* Staff lost per week due to retirement, death, quitting, etc

eng exp ratio = (total engineers - Rookie Engineers) / total engineers
* dimensionless

D eng hiring delay = 4
* weeks
* Time to hire new mechanics.

ENG LAYOFFS from OT =F Eng Layoffs from OT(eng OT frac ratio)

eng OT frac ratio = frac eng overtime / D target frac eng OT
* dimensionless

eng plan rev avail = engineer plans * DR plans rev per eng per week

eng info rev avail = engineer info * DR info rev per eng per week

eng maint rev avail = engineer maint * DR maint rev per eng per week * work orders/week

engineer maint = frac eng maint * total engineers * EFF NRC INV MGT ENG
* people
* Engineers for maintenance.

engineer plans = frac eng plans * total engineers
* people
* Engineers for plans.

engineer info = DR frac eng info * total engineers
* people
* Engineers for information.

Engineer up to speed = Rookie Engineers / D time to train engs
* people/week
* Maintenance staff loss.

DR frac eng info = 0.3
* dimensionless

frac eng maint = 0.5 + 0.714 * (0.3 - DR frac eng info)
* dimensionless

frac eng plans = 0.2+0.286 * (0.3 - DR frac eng info)
* dimensionless

DR info rev per eng per week = 16
* information/week/engineer

D eng layoff fraction = 0
* dimensionless
* The fraction of engineers to be laid off for the test at 100 weeks.

DR maint rev per eng per week = 8
  * maintenance/week/engineer

NEW ENG HIRING from OT = F New Eng Hiring from OT(frac eng overtime / D target frac eng OT + 1e-005)
  * dimensionless

new hiring switch eng = IF THEN ELSE(total engineers>max eng, 0, 1)
  * dimensionless
  * 1 allows new maintenance staff to be hired when average overtime becomes excessive. 0 disallows any new hiring because of increased workloads.

DR plans rev per eng per week = 16
  * plans/week/engineer

Pro Engineers = SINTEG(Engineer up to speed-Pro engineer loss - Promotions, INT Pro Engineers,0,:NA:,:NA:,:NA:,:NA:)
  * people
  * Professional engineering staff.

Promotions = 0
  * people/week

Rookie Engineers = SINTEG(Engineer hiring-Engineer up to speed, INT Rookie Engineers,0,:NA:,:NA:,:NA:,:NA:)
  * people
  * Total maintenance personnel, including planners.

D time to layoff engs = 12
  * weeks
  * Time to layoff engineers.

D time to train engs = 26
  * weeks
  * Time required to train engineers.

total engineers = (Pro Engineers + Rookie Engineers) * EFF REG ABAND TOT ENG and MGR
  * people

****

A. Engineer 2(view 25)

****

INT Ave Eng Overtime = DR eng standard hours * D target frac eng OT
  * hours/(week*person)
  * The initial value of average engineer overtime.

Ave Eng Overtime = INTEG(Chg in ave eng OT, INT Ave Eng Overtime)
  * hours/(week*person)
  * Average number of overtime hours worked. The averaging represents the process through which excessive overtime gradually causes fatigue and reduces productivity. The process of recovering from excessive overtime is also gradual.

Chg in ave eng OT = (ind eng overtime - Ave Eng Overtime) / D time to change ave eng OT
* hours/(week*person)/week
* Change in average overtime.

eng OT frac = eng tot work hours / DR eng standard hours
* dimensionless
*:SUPPLEMENTARY

EFF INFO WLD OT =F eff info wld OT(eng info workload)
* dimensionless
* The effect of info workload on overtime.

EFF MAINT WLD OT =F eff maint wld OT(eng maint workload)
* dimensionless
* The effect of maint work load on overtime.

EFF MOTIVATION ENG WO COMP =F eff motivation eng WO comp(SALP)
* dimensionless
* Effect motivation work order completion. This is the motivation factor on productivity based on good leadership. 1.0 is none 1.15 if full.

EFF OT FATIGUE ENG =F eff OT fatigue eng(Ave Eng Overtime)
* dimensionless
* The effect of overtime on productivity.

EFF PLAN WLD OT =F eff plan wld OT(eng plan workload)
* dimensionless
* The effect of plan workload on overtime.

EFF PROD PRES on ENG OT = F eff prod pres on E OT(IF THEN ELSE(Periodic Outage=1, 1.5, production pressure))
* dimensionless
* Effect production pressure on overtime. The effect of production pressure on overtime. If product demand is very high, there is pressure for maintenance to work overtime to get the equipment back on-line.

EFF WLOAD ENG WO COMP =F eff wload eng wo comp(eng workload)
* dimensionless
* Effect of workload on work order completion. As work slows down, the staffs desire to complete work orders decreases. It represents peoples desire to make the available work fit the available time.

eng info workload = eng info WTB / (engineer info + 1)

eng info WTB = Info Eng WTB / DR info rev per eng per week

eng maint workload = eng maint WTB / (engineer maint + 1)

eng maint WTB = (Schd Work Order[S1] + Unschd Work Order[U1]) / DR maint rev per eng per week

eng plan workload = eng plan WTB / (engineer plans + 1)

eng plan WTB = Plans Wait Eng Rev / DR plans rev per eng per week

DR eng standard hours = 40
* hours/(week*person)
* The standard number of hours worked per week per maintenance staff(mechanic, electrician, pipefitter, machinist, etc)

eng tot work hours = Ave Eng Overtime + DR eng standard hours
* hours/(week*person)
* Total work hours

eng workload = (eng info workload * engineer info + eng plan workload * engineer plans + eng maint workload * engineer maint) / (total engineers + 1)

frac eng overtime = D target frac eng OT * EFF PROD PRES on ENG OT * ((EFF INFO WLD OT * engineer info + EFF MAINT WLD OT * engineer maint + EFF PLAN WLD OT * engineer plans) / total engineers)
* dimensionless
* Actual fraction overtime. Overtime for maintenance staff in terms of percent of standard work week.

human effs on work comp eng = EFF MOTIVATION ENG WO COMP*SMOOTHI(EFF OT FATIGUE ENG, 4, 1)*EFF WLOAD ENG WO COMP
* dimensionless
* Human effect on work order completion. Product of motivation, fatigue and workload effects on worker performance.

ind eng overtime = DR eng standard hours * frac eng overtime
* hours
* Indicated maintenance overtime that is worked (actual week by week value). As of 8/4/ it includes the tr .ining hours.

D target frac eng OT = 0.125
* dimensionless
* Target fraction engineer overtime.

D time to change ave eng OT = 2
* weeks
* Time to change average overtime. This is the time to adjust average overtime. It determines how quickly average overtime adjusts to actual overtime.

****

A. Engineer 3(view 26)

****

ratio eng schd to unschd WO = MAX(Schd Work Order[S1] / (Unschd Work Order[U1] + Schd Work Order[S1] + 0.0001), 0.2)
* dimensionless

cost of eng OT = (Ave Eng Overtime * DR cost per OT hr) / 1e+006
* dollars/week
* Cost of each engineer to work overtime.

DR cost per OT hr = 50
* million dollars/hour
* Cost per overtime hour

eng info rev comp = eng info rev avail * human effs on work comp eng * EFF ESTAFF EXP
* (1 + D target frac eng OT* EFF INFO WLD OT) * EFF PROD PRES on ENG OT

eng plan rev comp = eng plan rev avail * human effs on work comp eng * EFF ESTAFF EXP
* (1 + D target frac eng OT * EFF PLAN WLD OT) * EFF PROD PRES on ENG OT

eng schd WO rev comp = eng maint rev avail * human effs on work comp eng
* ratio eng schd to unschd WO * EFF ESTAFF EXP
* (1 + D target frac eng OT * EFF MAINT WLD OT) * EFF PROD PRES on ENG OT
* work orders/week

eng unschd WO rev comp = 2 * eng schd WO rev comp* (1 - ratio eng schd to unschd WO)
/ ratio eng schd to unschd WO

****

A. Equipment flows(view 1)

****

INT Eq Bdwn = 0.15 * Total Equipment in Plant
* Equipment
* Initial equipment brokendown.

INT Eq Tag PM = 0.0234 * Total Equipment in Plant
* Equipment
* Initial equipment tagged for preventative maintenance.

Equip broke to on line = on-line bdwns - Completed unschd WO[U4] * DR equip per WO
* Equipment/week
* In the positive direction, the flow is equipment that breaks down. In the negative direction, the flow is equipment that is repaired.

Equip Brokendown = SINTEG(+Tagged PM equip bdwn+Equip broke to on line
,INT Eq Bdwn,0,:NA:,:NA:,:NA:,:NA:)
* Equipment
* Equipment broken down and in the process of being repaired. Unscheduled work is done on broken equipment.

Equip Perceived Fully Function = SINTEG(-Equip broke to on line-Equip PM to on line
,INT Eq PFF,0,:NA:,:NA:,:NA:,:NA:)
* Equipment
* Equipment that is perceived to be fully functional.

DR equip per WO = 4
* Equipment/work order
* The average number of pieces of equipment covered by a work order.

Equip PM to on line = equip req tdwn for insp - Completed schd WO[S5] * DR equip per WO
- schd WO aw eq forgotten * DR equip per WO
* Equipment/week
* The positive flow is takedowns of equipment. The negative flow is the completion of scheduled work and the process of losing information that equipment is defective.

Equip Tagged for PM = SINTEG(Equip PM to on line-Tagged PM equip bdwn
,INT Eq Tag PM,0,:NA:,:NA:,:NA:,:NA:)

* Equipment/week
* The number of pieces of equipment identified as defective by the predictive or preventive program including all casual noticing of defects.

INT Eq PFF = 0.8266 * Total Equipment in Plant

* Equipment
* Initial equipment perceived fully functional.

Tagged PM equip bdwn = tagged PM equip bdwns

* Equipment/week
* Equipment in the predictive and preventive system that breaks down while it is waiting to be inspected or repaired.

Total Equipment in Plant = 13400 * 5

* Equipment
* Total equipment in plant. Exogenous input to be correlated to size of plant.

WO for bdwn PM equip = SMOOTH(Tagged PM equip bdwn/DR equip per WO,5)

* work order/week
* Work orders for Broken Down PM Equipment currently applies to PM equipment under inspection, which requires a WO, and not PM equipment operating in plant. This may present a flaw in logic, CHECK.

****

A. Inspections 1(view 20)

****

dfct equip req tdwn = equip ID dfct dinsp WT tdwn + equip ID dfct minsp WT tdwn

* Equipment/week
* Equipment identified defective without takedown.

equip ID dfct dinsp WT tdwn = dfct equip ID dfct dinsp WT tdwn + non dfct equip ID dfct dinsp WT tdwn

* Equipment/week
* All equipment that is identified as being defective during mandatory on-line inspections includes equipment that is actually defective and equipment that was incorrectly identified as defective.

equip ID dfct minsp WT tdwn = dfct equip ID dfct minsp WT tdwn + non dfct equip ID dfct minsp WT tdwn

* Equipment/week
* All equipment that was identified as being defective during discretionary on-line inspection routine includes actually defect equipment and misidentified equipment.

equip req tdwn for insp = equip ID dfct dinsp WT tdwn + equip ID dfct minsp WT tdwn + minsp W tdwn + dinsp W tdwn

* Equipment/week
* Total takedowns that are required from mandatory and discretionary inspections.

****

A. Inspections 2(view 21)

****

desired dinsp = (Equip Perceived Fully Function *DR frac equip insp / DR ave time between dinsp) * EFF NRC REP MDINSP * EFF NRC REGD MDINSP

* inspections/week
* Desired discretionary inspections.

desired staff for dinsp = (desired dinsp * DR ave time for dinsp) / DR standard hours

* people
* Desired mechanics for discretionary inspections.

dfct equip dinsp WT tdwn = dinsp WT tdwn * FRAC EQUIP DFCT DSC INSP

* Equipment/week
* Defective equipment in discretionary inspection without takedown.

dfct equip ID dfct dinsp = dfct equip ID dfct dinsp WT tdwn + dfct equip ID dfct dinsp W tdwn

* Equipment/week
* Defective equipment identified as defective during discretionary inspections.

dfct equip ID dfct dinsp W tdwn = dinsp W tdwn * FRAC EQUIP DFCT DSC INSP

* Equipment/week
* Defective equipment identified defective during discretionary inspection with takedown.

dfct equip ID dfct dinsp WT tdwn = dfct equip dinsp WT tdwn * (1- DR prob miss dfct dinsp)

* Equipment/week
* Defective equipment identified defective during discretionary inspections without takedown.

dfct equip ID dfct minsp = dfct equip ID dfct minsp WT tdwn + dfct equip ID dfct minsp W tdwn

* Equipment/week
* Defective equipment identified as defective during mandatory inspection.

dfct equip ID dfct minsp W tdwn = minsp W tdwn * FRAC EQUIP DFCT MAND INSP

* Equipment/week
* Defective equipment identified defective during mandatory inspections with takedown. Mandatory inspections of equipment that require a takedown for the inspections that are defective mand inspect req tdown defective.

dfct equip ID dfct minsp WT tdwn = dfct equip minsp WT tdwn * (1 - DR prob miss dfct minsp)

* Equipment/week
* Defective equipment identified as defective during mandatory inspections without takedown. Mandatory inspections, not requiring a takedown , which find a defect and result in a takedown to repair the equipment mand inspect defect to inspect.

dfct equip minsp WT tdwn = minsp WT tdwn * FRAC EQUIP DFCT MAND INSP

* Equipment/week
* Defective equipment mandatory inspections without takedown. The number of mandatory inspections, not requiring a takedown, that are done on defective equipment.

dfct ID from insp = dfcts equip ID insp * dfcts per dfct equip PFF

* defects/week
* Defects identified from inspections. Total defects identified by inspections both discretionary and mandatory.

dfcts equip ID insp = dfct equip ID dfct dinsp +dfct equip ID dfct minsp

* Equipment/week
* Defective equipment identified inspections. Total takedowns of equipment that is actually defective.

dinsp W tdwn = (staff dinsp W tdwn * DR standard hours) / DR ave time for dinsp

* Equipment/week
* Discretionary inspections that require a takedown for the inspection.

dinsp WT tdwn = staff dinsp WT tdwn * DR standard hours / DR ave time for dinsp

* inspections/week
* Discretionary inspections without takedown. The number of discretionary inspections performed that don't require a takedown for the inspections. Calculated by taking manpower available times average man-hours per week divided by man-hours necessary.

DR ave time between dinsp = 20

* weeks
* Average time between discretionary inspection.

DR ave time between minsp = (25.5 / EFF NRC MINSP) * social to plant switch
+ (30 * (1-social to plant switch))

* weeks
* Average time between mandatory inspections for each piece of equipment. Changed from 30/ to 20/ +10/

DR ave time for dinsp = 5 / DR equip per WO

* hours/inspection
* The average time for a discretionary inspection. The average here is for all equipment inspected from feedwater pumps to motor operated valves. Here, average time is a function of equipment per work order; this is based on an assumption about the level of dissaggregation of equipment on work orders: iE. an equipment per work order of 1 implies, for example, a motor operated valve is one unit where as an equipment per work order of 3 implies that the same mob is separated into three pieces-- the motor being one piece, the gear box another, and the valve a third. Hence, fewer pieces of equipment per work order leads to more time per work order: the amount of aggregation or disaggregation of equipment.

DR ave time for minsp = 10 / DR equip per WO

* hours/inspection
* Average time to do mandatory inspection.

DR frac dinsp req tdwn = 0.15

* dimensionless
* Fraction of discretionary inspections that require a takedown to do the inspection.

DR frac equip insp = 0.6

* dimensionless
* The fraction of total equipment that can be inspected with the current technology used in the area and deemed justifiable.

DR frac minsp req tdwn = 0.3

* dimensionless
* The fraction of mandatory inspections that require a takedown for the inspection.

DR prob false pos = 0.05
* dimensionless
* Probability of finding a false positive when doing an inspection.

DR prob miss dfct dinsp = 0.15
* dimensionless
* Probability of missing a defect in a discretionary inspection.

DR prob miss dfct minsp = 0.03
* dimensionless
* The probability that a mandatory inspection misses a defective piece of equipment.

FRAC EQUIP DFCT DSC INSP =F frac equip dfct dsc insp(FRAC EQUIP PFF DFCT)
* dimensionless
* This calibrates the expected fraction of finding a defect when you inspect a piece of equipment for discretionary inspections.

FRAC EQUIP DFCT MAND INSP =F frac equip dfct mand insp(FRAC EQUIP PFF DFCT)
* dimensionless
* Fraction mandatory inspections defective.

The fraction of equipment receiving a mandatory inspection that is in fact defective.

frac equip req minsp = MIN((0.2 * EFF NRC MINSP) * (0.6 * EFF NRC INV MINSP)
* EFF NRC REGD MDINSP * social to plant switch
+ (0.1 * (1-social to plant switch)), 1)
* dimensionless
* Fraction equipment requiring mandatory inspection.

minsp = Equip Perceived Fully Function * frac equip req minsp / DR ave time between minsp
* inspections/week
* Mandatory equipment inspections.

Pieces of plant equipment requiring mandatory inspections.

minsp staff = (minsp * DR ave time for minsp) / DR standard hours
* people
* Mechanics allocated to mandatory inspections.

minsp W tdwn = minsp * DR frac minsp req tdwn
* Equipment/week
* Mandatory inspection with takedown. Mandatory inspections that require a takedown for the inspection.

minsp WT tdwn = minsp - minsp W tdwn
* inspections/week
* Mandatory equipment inspections without takedown.

non dfct equip ID dfct dinsp WT tdwn = dinsp WT tdwn * (1-FRAC EQUIP DFCT DSC INSP)
* DR prob false pos
* Equipment/week
* Non-defective equipment identified defective during discretionary inspections without takedowns.

non dfct equip ID dfct minsp WT tdwn = minsp WT tdwn * (1-FRAC EQUIP DFCT MAND INSP)
* DR prob false pos

* Equipment/week
* Non-defective equipment identified defective during mandatory inspections without takedowns. Equipment takedowns resulting from mandatory inspections without takedown that have no defects.

social to plant switch = 1

* dimensionless
* 1 connects social pressure/safety regulation section to plant model.
0 disconnects social pressure/safety regulations section from plant model.

staff dinsp W tdwn = dinsp staff * DR frac dinsp req tdwn

* people
* Staff discretionary inspection with takedown. Mechanics allocated to discretionary inspections that require a takedown.

staff dinsp WT tdwn = dinsp staff - staff dinsp W tdwn

* people
* Staff discretionary inspection without takedown. Mechanics allocated to discretionary inspections where the inspection does not require a takedown.

****

A. Learning curve and Training(view 6)

****

CA completed = CA validated[PRO] + CA validated[TRA]

* corrective action/week
* This is the number of corrective actions completed in the industry.

Completed PM rate[WO] = IF THEN ELSE((Time>program start), Completed schd WO[S5], 0)
Completed PM rate[BE] = capacity on-line
Completed PM rate[DR] = IF THFN ELSE((Time>program start), Parts consumed, 0)
Completed PM rate[OE] = capacity on-line
Completed PM rate[IN] = CA completed
Completed PM rate[FO] = plant force out

DR base frac mat dfct at delvry = 0.25

* dimensionless
* Base fraction materials defective at delivery.

learning curve[WO] = 0.01 * training hours * EFF Learning Curve MECF
learning curve[BE] = 0.01 * training hours
learning curve[DR] = 0.01 * training hours
learning curve[OE] = 0.05/3 * training hours
learning curve[IN] = 0.05/3 * training hours
learning curve[FO] = 0.1/3 * training hours

INT CUM Correct Action[WO] = 50 * 52
INT CUM Correct Action[BE] = 75 * 52
INT CUM Correct Action[DR] = 100 * 52
INT CUM Correct Action[OE] = 75 * 52
INT CUM Correct Action[IN] = 20 * 52
INT CUM Correct Action[FO] = 1

INT Event Occurance Rate[WO] = DR base dfcts from wmanship
INT Event Occurance Rate[BE] = DR base dfcts ops per week
INT Event Occurance Rate[DR] = DR base frac mat dfct at delvry
INT Event Occurance Rate[OE] = 0.019
INT Event Occurance Rate[IN] = 0.019
INT Event Occurance Rate[FO] = 0.25 / 52

CUM Correct Action[XLearning and Training] = SINTEG(Completed PM rate[XLearning and Training],
INT CUM Correct Action[XLearning and
Training],0,:NA:,:NA:,:NA:,:NA:)

Rate decreasing[XLearning and Training] =IF THEN ELSE((Time>52),
Event Occurance Rate[XLearning and Training]
* MOD learning curve[XLearning and Training]
* frac analysis[XLearning and Training], 0)

frac analysis[XLearning and Training] = ZIDZ(Completed PM rate[XLearning and Training] ,
CUM Correct Action[XLearning and Training])

Event Occurance Rate[XLearning and Training] = SINTEG(-Rate decreasing[XLearning and Training],
INT Event Occurance Rate[XLearning and
Training],0,:NA:,:NA:,:NA:,:NA:)

MOD learning curve[XLearning and Training] = - LN(1-learning curve[XLearning and Training])
/ LN(2)

EFF Learning Curve MECF =F EFFLREX(DR mech experience cost factor)
* dimensionless
* The effect on the learning curve of mechanic experience cost factor.

DR mech experience cost factor = 1.05
* dimensionless
* Mechanic experience cost factor. A multiplier which MGT can use to hire more experienced mechanics for more money.

program start =0
* dimensionless
* Program start date.

****

A. Maintenance staff (Mechanics) 1(view 16)

****

init planning staff = 25 * 3
* people
* Initial planning staffs.

frac Mstaff planners = init planning staff / INT Maintenance Staff
* dimensionless
* The fraction of maintenance personnel dedicated to planning. Exogenous variable.

INT Maintenance Staff = 340

DR attrition = 0.05 * Maintenance Staff
* people/week
* The staff lost per week due to retirement, death, quitting, etc.

D bud layoff time = 6
* weeks
* Time it takes to layoff mechanics due to budgeting.

budget Mstaff layoffs = IF THEN ELSE(Maintenance Staff > max Mstaff, Maintenance Staff - max Mstaff, 0)
* people

D contractor hiring = 150
* people
* Number of contractors hired

contractor pulse = SMOOTHI(D contractor hiring * Outage start, 1, 0)
* dimensionless

dinsp staff = MIN(Mstaff avail maint work * max frac avail Mstaff alloc disc insp, desired staff for dinsp)
* people
* Mechanics allocated to doing discretionary inspections.

D layoff fraction = 0
* dimensionless
* Percentage of the mechanics that will be laid off for the test.

layoff switch = 1
* dimensionless
* This switch layoff 25% of workers at week 100.

Mstaff hiring = DR attrition + (NEW STAFF HIRING * new hiring switch / D maint hiring delay) + contractor pulse
* people/week
* The hiring of new mechanics

D maint hiring delay = 8
* weeks
* Time to hire new mechanics.

Mstaff avail maint work = Maintenance Staff - planners maint
* workers
* Maintenance staff available for maintenance work

Mstaff avail mech work = Mstaff avail maint work - total insp manpower
* workers
* Maintenance staff available for actual work on machinery, whether mechanical, electrical, instrumentation, etc.

Mstaff layoffs = D layoff fraction * layoff switch
* percentage
* This is policy variable that is an exogenous function of time.

Maintenance Staff = SINTEG(Mstaff hiring-Mstaff loss, INT Maintenance Staff,0,:NA:,:NA:,:NA:,:NA:)
* people
* Total Maintenance personnel, including planners.

max frac avail Mstaff alloc disc insp = frac lab bud alloc disc insp
* dimensionless
* Maximum fraction available maintenance staff allocated discretionary inspections. Every week a certain number of discretionary inspections come due. These inspections require mechanics, for example, 10. This variable represents the fraction of the ten mechanics the plant is willing to give up for the inspections. For example, if the fraction is 0.8, 8 mechanics would be allocated to discretionary inspections.

Mstaff loss = DR attrition + (Mstaff layoffs * Maintenance Staff) / TIME STEP
* PULSE(100, TIME STEP) + SMOOTHI(Outage finish * D contractor hiring * 0.5, 2, 0)
+ (budget Mstaff layoffs / D bud layoff time)
* people/week
* Maintenance staff loss.

new hiring switch = IF THEN ELSE(Maintenance Staff > max Mstaff, 0, 1)
* dimensionless
* 1 allows new maintenance staff to be hired when average overtime becomes excessive. 0 disallows any new hiring because of increased workloads.

NEW STAFF HIRING = F New Staff Hiring(Ave Overtime)

planners maint = Maintenance Staff * frac Mstaff planners
* workers
* This is the number of maintenance workers allocated to planning.

total insp manpower = dinsp staff + minsp staff
* people
* Total maintenance manpower allocated to inspections.

****
A. Maintenance staff (Mechanics) 2(view 17)
****

INT Ave Overtime = 5
* hours/(week*person)
* The initial value of average overtime.

Ave Overtime = INTEG(Chg in ave OT, INT Ave Overtime)
* hours/week/person
* Average number of overtime hours worked. The averaging represents the process through which excessive overtime gradually causes fatigue and reduces productivity. The process of recovering from excessive overtime is also gradual.

Chg in ave OT = (ind OT - Ave Overtime) / D time to change ave OT
* hours/(week*person)/week
* Change in average overtime.

EFF MAIN OT INFO =F EFF main OT info(Ave Overtime)
* dimensionless

EFF MOTIVATION WO COMP =F eff motivation WO comp(Time)
* dimensionless
* This is the motivation factor on productivity based on good leadership. 1.0 is none 1.15 if full.

EFF OT FATIGUE OA =F Eff OT fatigue OA(Ave Overtime)
* dimensionless

EFF OT FATIGUE WO COMP =F eff OT fatigue wo comp(Ave Overtime)
* dimensionless
* The effect of overtime on productivity.

EFF PROD PRES on OT = F eff prod pres on OT(production pressure)
* dimensionless
* The effect of production pressure on overtime. If product demand is very high, there is pressure for maintenance to work overtime to get the equipment back on-line.

EFF WLOAD OT = F eff wload OT(workload)
* dimensionless
* If the number of weeks of maintenance work is high, there is pressure to work over time to get the work done.

EFF WLOAD WO COMP =F eff wload wo comp(workload)
* dimensionless
* As work slows down, the staff's desire to complete work orders decreases. It represents peoples desire to make the available work fit the available time.

EFF OT DG=F Eff ot DG(Ave Overtime)
* dimensionless

frac OT = D target frac OT * EFF WLOAD OT * EFF PROD PRES on OT
* dimensionless
* Actual fraction overtime for maintenance staff in term of percent of standard work week.

human effs on WO comp = EFF MOTIVATION WO COMP
* (SMOOTHI(EFF OT FATIGUE WO COMP, 6, 1))
* EFF WLOAD WO COMP
* dimensionless
* Product of motivation, fatigue and workload effects on worker performance.

ind OT = DR standard hours * frac OT
* hours
* Indicated maintenance overtime that is worked. As of 8/4 it includes the training hours.

DR standard hours = 40
* hours/(week*person)
* The standard number of hours worked per week per maintenance staff.

D target frac OT = 0.1
* dimensionless
* Target fraction overtime.

D target weeks work = 2
* weeks
* The desired or target backlog, in time, of work to be maintained.

D time to change ave OT = 1
* weeks
* This is the time to adjust average overtime. It determines how quickly average overtime adjusts to actual overtime.

total work hrs = DR standard hours + Ave Overtime
* hours/(week*person)
* Total work hours.

training hours = DR frac bud training * DR standard hours
* hours/(week*person)
* This is the number of hours per week that mechanic spend in training. It increases their learning curve but also costs money and takes them off jobs. The bene..s should be long time then: It also increases experience faster. Its effect is on the learning curves of other areas.

workload = weeks work TBD / D target weeks work
* dimensionless
* workload.

****

A. Manager 1(view 27)

****

Mgr loss = DR attrition mgr + (mgr layoff /D time to layoff mgrs)+ bud layoff mgr / D time to layoff mgrs
* people/week
* Management staff loss.

mgr layoff = IF THEN ELSE(Time=100, D mgr layoff fraction * total managers * D time to layoff mgrs / TIME STEP, MGR LAYOFFS from WORKLOAD)
* people
* Manager layoffs. This is a policy variable that is an exogenous function of time.

Mgr hiring = DR attrition mgr + (NEW MGR HIRING from OT * new hiring switch 2 / D mgr hiring delay)
* people/week
* The hiring of new management staff.

INT Pro Managers =(1/11) * (total engineers + INT Maintenance Staff)
* people
* The initial value of pro management staff

new hiring switch 2 = IF THEN ELSE(max mgr>total managers, 0, 1)
* dimensionless
* 1 allows new manager to be hired when average overtime become excessive.
0 disallows any new hiring because of increased workloads.

frac mgr maint = 1- frac mgr info - DR frac mgr fin

INT Managers = 0
* people
* The initial value of management staff

DR attrition mgr = 0.001 * Pro Managers
* people/week
* Staff lost per week due to retirement, death, quitting, etc.

bud layoff mgr = IF THEN ELSE(total managers > max mgr, total managers - max mgr, 0)

EFF MGT STAFF EXP = F Eff Mgt staff exp((total managers - Rookie Managers) / total managers)

DR frac mgr fin = 0.2

frac mgr info = DR frac eng info / 2

D mgr layoff fraction = 0
* dimensionless
* The fraction of managers to be laid off for the test at 100 weeks.

DR info rev per mgr per week = 9

DR maint rev per mgr per week = 20

managers fin = total managers * DR frac mgr fin
* people
* Managers for finance

managers info = total managers * frac mgr info
* people
* Managers for info

managers maint = total managers * frac mgr maint * EFF NRC INV MGT ENG
* people
* Managers for maintenance.

mgr info rev avail = managers info * DR info rev per mgr per week

MGR LAYOFFS from WORKLOAD =F Mgr Layoffs from Workload(mgr OT ratio)
* dimensionless

mgr maint rev avail = managers maint * DR maint rev per mgr per week

mgr OT ratio = desired frac mgr OT / D target frac mgr OT

D mgr hiring delay = 4
* weeks
* Time to hire new management staff

mgr no fin = total managers - managers fin
* people
* Managers except for finance

D mgr time to up to speed = 26
* weeks

Mgr up to speed = Rookie Managers / D mgr time to up to speed
* people/week

NEW MGR HIRING from OT =F New Mgt Hiring from OT(desired frac mgr OT / D target frac mgr OT)
* dimensionless

Pro Managers = SINTEG(+Mgr up to speed-Mgr loss, INT Pro Managers,0,:NA:,:NA:,:NA:,:NA:)
* people
* Total management staff.

Rookie Managers = SINTEG(Mgr hiring-Mgr up to speed, INT Managers,0,:NA:,:NA:,:NA:,:NA:)
* people
* Total new management personnel.

D time to layoff mgrs = 8
* weeks

total managers = (Pro Managers + Rookie Managers) * EFF REG ABAND TOT ENG and MGR
* people
* Total managers

****

A. Manager 2(view 28)

****

ind mgr OT = DR mgr standard hours * desired frac mgr OT
* hours
* Indicated management overtime that is worked. As of 8/4 it includes the training hours.

INT Ave Mgr OT = DR mgr standard hours * D target frac eng OT
* hours/(week*person)
* The initial value of average manager overtime.

human effs on work comp mgr = EFF MOTIVATION MGR WO COMP
*SMOOTHI(EFF OT FATIGUE MGR, 4, 1)
*EFF WLOAD MGR WORK WO COMP
* dimensionless
* Product of motivation, fatigue and workload effects on worker performance.

mgr total work hours = DR mgr standard hours + Ave Mgr OT
* hours/(week*person)
* Total work hours.

DR mgr standard hours = 40
* hours/(week*person)
* The standard number of hours worked per week per managers.

mgr OT frac = mgr total work hours / DR mgr standard hours
*:SUPPLEMENTARY

Ave Mgr OT = INTEG(Chg in ave mgr OT, INT Ave Mgr OT)

* hours/(week*person)
* Average overtime. Average number of overtime hours worked. The averaging represents the process through which excessive overtime gradually causes fatigues and reduces productivity. The process of recovering from excessive overtime is also gradual.

Chg in ave mgr OT = (ind mgr OT - Ave Mgr OT) / D time to change mgr OT

* hours/(week*week*person)
* Change in average overtime.

desired frac mgr OT = D target frac mgr OT * EFF PROD PRES on MGR OT / EFF PROD PRES on MGR OT * ((EFF MGR INFO WLD OT * managers info + EFF MGR MAINT WLD OT * managers maint) / mgr no fin)

* dimensionless
* Overtime for maintenance staff in terms of percent of standard work week.

EFF MGR INFO WLD OT =F eff mgr info wld OT(mgr info workload)

* dimensionless

EFF MGR MAINT WLD OT =F eff mgr mnt wld OT(mgr maint workload)

* dimensionless

EFF MOTIVATION MGR WO COMP =F eff motivation mgr WO comp(SALP)

* dimensionless
* This is the motivation factor on productivity based on good leadership. 1.0 is none 1.15 if full.

EFF OT FATIGUE MGR =F eff OT fatigue mgr(Ave Mgr OT)

* dimensionless
* The effect of overtime on productivity.

EFF PROD PRES on MGR OT =F eff prod pres on Mgt OT(IF THEN ELSE((Periodic Outage=1), 1.5, production pressure))

* dimensionless
* Effect production pressure on overtime. If product demand is very high, there is pressure for maintenance to work overtime to get the equipment back on-line.

EFF WLOAD MGR WORK WO COMP =F eff wload mgr work wo comp(mgr workload)

* dimensionless
* Effect of workload on work order completion. As work slows down, the staff's desire to complete work orders decreases. It represents people desire to make the available work fit the available time.

mgr info workload = mgr info WTB / (managers info + 1)

mgr info WTB = SMOOTH(Info Mgr WTB/DR info rev per mgr per week, 1)

mgr maint workload = mgr maint WTB / managers maint

mgr maint WTB = SMOOTH((Schd Work Order[S2] + Unschd Work Order[U2] / 2) / DR maint rev per mgr per week, 2)

mgr workload = (managers info * mgr info workload + managers maint * mgr maint workload) / (mgr no fin + 1)

mgr ratio schd to unschd WO = MAX((Schd Work Order[S2] / (Schd Work Order[S2]
+ Unschd Work Order[U2] + 1)), 0.2)

D target frac mgr OT = 0 125
* dimensionless
* Target fraction overtime.

D time to change mgr OT = 2
* weeks
* This is the time to adjust average overtime. It determines how quickly average overtime adjusts to actual time.

****
A. Manager 3(view 29)
****

mgr info rev comp = mgr info rev avail * human effs on work comp mgr * EFF MGT STAFF EXP
* (1 + D target frac mgr OT* EFF MGR MAINT WLD OT)
* EFF PROD PRES on MGR OT

mgr schd WO rev comp = mgr maint rev avail * human effs on work comp mgr
* mgr ratio schd to unschd WO * EFF MGT STAFF EXP
* (1 + D target frac mgr OT * EFF MGR INFO WLD OT)
* EFF PROD PRES on MGR OT
mgr unschd WO rev comp = 2 * mgr schd WO rev comp
* (1-mgr ratio schd to unschd WO) / mgr ratio schd to unschd WO

****
A. Materials Specification(view 22)
****

Specs created = new parts + DR CA per reg * New reg evals completed
+ CA cmplted[MOD] *D schd WO per mod CA
* specs/week
* New specs created.

INT New Equipment = Total Equipment in Plant * 0.2
* Equipment
* The initial value of new equipment.

INT Quality of Specs = Spec * D init quality spec
* quality specs/week
* The initial value of quality of specifications.

INT Spec = 25000
* specs
* The initial value of spec.

Aging equip =New Equipment / D aging time
* Equipment/week
* Aged equipment.

D aging time = 26
* weeks
* Time for equipment to go from new to old just like the rest of the equipment on average. A guess on MGT's part.

ave qual specs = Quality of Specs / Spec
* quality specs
* Average quality of specs.

ave imp qual spec = (100 - ave qual specs) * ave qual spec switch * 0.8
* dimensionless
* The average improvement per upgrade specification. It says that for each reject for which the specs were upgraded the increase in spec quality will be 80% of the difference between the old spec quality and 100% quality spec since each spec upgrade will not be perfect.

ave qual spec switch = 1
* dimensionless
* Average quality specification switch. 1 leads to automatic improvement in parts quality. 0 holds quality at initial value.

Bought equip = (bought eq cap inv$ / DR dollar per new eq) / D buy time
* Equipment/week
* Bought equipment.

D buy time = 2
* weeks
* Time to install new equipment.

DR cost new cap part = 2.5
* million dollars/part
* This is the cost of purchasing a new capital equipment and adding the resulting new spec for that equipment to the total. New capital equipment will have less wear and tear and have less of a chance breaking down.

DR cost per part des = 0.025
* million dollars/part
* Cost of improving a specification of part. It represents the cost of investing in improving gaskets to MCPs. Since the utility buys millions of gaskets and only one or two MCPs this number averages out. It also represents the cost of investing in a program to improve competitiveness between suppliers and testing and researching better products.

DR dollar per new eq = 0.1
* million dollars/Equipment
* This is the cost for each piece of new equipment. New equipment effect is felt under defects from ops. The assumption is that new equipment breaks down at a lower rate than old equipment. This cost assumes that the cost for new cap equipment is high because the small equipment can assumed to come under the PMS program. Whole new equipment is assumed here to be complex and effect the chance of breakdown not to completely fix a machine.

FRAC RTRND GIVEN DFCT =F frac rtrnd given dfct(ave qual specs)
* dimensionless
* Fraction returned given a defect. The fraction of materials that are returned given that they have a defect.

D init quality spec = 60
* specs
* Quality of the initial spec for a new part.

New Equipment = SINTEG(+Bought equip-Aging equip, INT New Equipment,0,:NA:,:NA:,:NA:,:NA:)
* Equipment
* The number of new equipment.

DR new part des inv = 1.5*5
* million dollars
* Investment in new part design in order to reduce defect generation rate. This discretionary parameter will provide a delayed improvement in quality. Management can improve parts in general. Assumed to be 1.5 million dollars as a reasonable investment in parts quality.

new parts = New Part Cap Inv $ /DR cost new cap part
* parts
* This represents the number of parts which are new, thus representing new specifications required.

Quality imp by design = Specs created * D init quality spec * SPEC UPGRADE PER PART
* quality specs/week
* The increase in spec quality from creating new specs.

Quality upgrades = D specs upgraded * ave imp qual spec
* quality specs/week
* The improvement in spec quality from upgrading parts requirements.

Quality of Specs = INTEG(Quality imp by design+Quality upgrades
, INT Quality of Specs)
* quality specs
* Quality of specifications.

rejects = deliveries * frac dfct parts rtrnd
* Materials that are delivered and rejected.

Spec = INTEG(Specs created, INT Spec)
* specs
* Specifications.

SPEC UPGRADE PER PART =F Spec upgrade per part(DR new part des inv / DR cost per part des)
* dimensionless
* This represent the multiplication on initial spec requirements that investment in new and better part designs by the utility will have. It could also represent money invested in more competitive operations such as seeking out better products since this costs money also. The output is an S shaped curve which will represent and increase or decrease in percentage defects from the initial defect % of 60%.

D specs upgraded = rejects * 0.2
* percentage
* This represents the percentage of rejects which will have their specs upgrades, 20% because the large majority of defects will be returned without any increase in specs believing that they are one time defects.

****

A. Mechanics time allocation(view 18)

****

ind manweeks unschd work = unschd WO to work * WO hrs per unschd WO / total work hrs
* weeks*person
* Indicated manweeks unscheduled work.

DR base frac schd WO maint hrs = 0.27
* dimensionless
* Percent of mechanics hours allocated top wrench time if none of the work is planned.

DR base frac unschd WO maint hrs = 0.25
* dimensionless
* For unscheduled work orders, the percent of mechanic time that goes to wrench hours if none of the work is planned.

EFF SCHD PLANNING on MAINT HRS =F eff schd planning on maint hrs(frac schd wip W plan)
* dimensionless
* The effect of planning on the fraction of mechanic time allocated to wrench time in scheduled work.

frac manweeks work TBD schd = manweeks schd work / (total manweeks work TBD+0.1)
* dimensionless
* The fraction of the maintenance staff that is allocated to scheduled work.

frac schd WO maint hrs = MAX(DR base frac schd WO maint hrs
* EFF SCHD PLANNING on MAINT HRS, 0.02)
* dimensionless
* Percent of mechanics hours going to wrench time for scheduled work.

frac unschd WO maint hrs = MAX(DR base frac unschd WO maint hrs
* EFF UNSCHD PLAN PCT HR WTIME, 0.02)
* dimensionless
* The percent of unscheduled work hours that go to wrench hours.

ind manweek schd work = schd WO to work * WO hrs per schd WO / total work hrs
* weeks*person
* Indicated manweeks scheduled work.

DR maint hrs per schd WO = 1.8
* hours/work order
* The number of wrench hours required per scheduled work order.

DR maint hrs per unschd WO = 1.8
* hours/work order
* The number of wrench hours required to complete an unscheduled work order.

manweeks schd work = ind manweek schd work / EFF OT FATIGUE WO COMP
* weeks*person
* The number of weeks worth of scheduled work.

manweeks unschd work = ind manweeks unschd work / EFF OT FATIGUE WO COMP
* weeks*person
* Manweeks of unscheduled work.

normal schd WO completed = SMOOTH(schd maint time/DR maint hrs per schd WO, 8)
* work orders/week
* Normal completion of work orders given the number of mechanics, wrench hours per work order, and hours worked.

schd maint time = schd mechanics * (DR standard hours + ind OT - training hours)
* frac schd WO maint hrs
* hours/week
* Wrench hours allocated to scheduled work.

schd mechanics = Mstaff avail mech work * frac manweeks work TBD schd
* people
* The number of mechanics allocated to perform scheduled work.

schd WO to work = MAX((schd WO RTBD BD - Unplanned Schd WO Mat Req), 10)
* work orders
* Work orders in progress or ready to work having no equipment or material delays.

total manweeks work TBD =manweeks schd work + manweeks unschd work
* weeks*person
* Total manweeks of work both scheduled and unscheduled.

EFF UNSCHD PLAN PCT HR WTIME =F unschd eff plan pct hr wtime(frac unschd wip W plan)
* dimensionless
* The effect of planning on the percent of time that goes to wrench time.

unschd maint time = unschd mechanics * (DR standard hours + ind OT - training hours)
* frac unschd WO maint hrs
* hours/week
* Wrench time to unscheduled work.

normal unschd WO completed = unschd maint time / DR maint hrs per unschd WO
* work orders/week
* The normal number of unsch work orders completed given the number of mechanics, hour worked, and the required number of wrench hours per work order.

unschd mechanics = Mstaff avail mech work * (1 - frac manweeks work TBD schd)
* people
* Mechanics allocated to unscheduled work.

unschd WO to work = MAX((Unschd Work Order[U4] - Unplanned Unschd WO Mat Req), 10)
* work orders
* Unscheduled work orders to work.

weeks work TBD = total manweeks work TBD / Mstaff avail mech work
* weeks
* Total weeks of maintenance work both scheduled and unscheduled.

WO hrs per schd WO = SMOOTH(DR maint hrs per schd WO / frac schd WO maint hrs, 2)
* hours/work order
* Total staff hours per scheduled work order, includes actual maintenance time, prep work, dress out, breaks, etc. Everything except planning personnel's time.

WO hrs per unschd WO = DR maint hrs per unschd WO / frac unschd WO maint hrs
* hours/work order
* Total staff hours per unscheduled work order, includes actual maintenance time, prep work, dress out, breaks, etc. Everything except planning personnel's time.

****
A. Periodic outage(view 12)
****

Outage start = IF THEN ELSE(time plus>start outage start :AND: time plus<(start outage start + TIME STEP), 1 / TIME STEP , 0)
* dimensionless

Outage finish = IF THEN ELSE(time plus>start outage finish:AND:time plus<(start outage finish+TIME STEP), 1 / TIME STEP, 0)
* dimensionless

start outage start = IF THEN ELSE(Time<=outage per, outage per, outage per + QUANTUM(Time, outage per + outage length))
* week
* Periodic function for outage start.

outage per = 10000
* weeks
* Refueling outage periodicity.

start outage finish = IF THEN ELSE(Time<=(outage per+outage length), outage per+outage length, +QUANTUM(Time, outage per + outage length))

EFF BEOL = F EFFBEOL(frac equip bdwn)
*:SUPPLEMENTARY

outage length = 5
* weeks
* Right now this set by the user. Needs to be a function of broken equipment at the beginning of the outage.

Periodic Outage = SINTEG(+Outage start-Outage finish, 0,0,:NA:,:NA:,:NA:,:NA:)
* dimensionless
* A function which says 1 = periodic outage 0 = fully operational

periodic outage function = 1
* dimensionless
* Refueling outage function. 1 if using refueling outages, 0 if not.
*:SUPPLEMENTARY

****

A. Planners(view 19)

****

Plan created = plans completed * (1-FRAC W PLANS)

* plans/week
* Creation new plans.

plan for review = Plan created + Plans Wait Eng Rev/ TIME STEP

plan ratio = (Library Plans + Plans Wait Eng Rev) / D max plans

* dimensionless
* A reference ratio to calculate the odds of having previous experience with the work presently being planned.

Plan reviewed = MIN(eng plan rev comp, plan for review)

* plans/week
* Review plans.

plans completed = planners avail plan * planner productivity

* work orders/week
* The number of plans that planners have completed/planned based on available number of planners and planner productivity.

planners needed to acq mat =total unplanned WO mat req * DR planners per WO mat req

* people
* Planners needed to acquire materials for unplanned WO requiring materials.

INT Library Plans = 100

* plans
* The initial value of library plans.

INT Plans Wait Eng Rev = 100

* plans
* The initial value of plans waiting reviewed.

DR base planner prod W plan = 30

* plans/(week*planner)
* Baseline planner productivity it there is an existing plan in the library.

DR base planner prod WT plan = 8

* plans/(week*planner)
* The number of work orders that a planner can do in one week if he starts without a plan in the library.

EFF WLOAD PLNNER PROD =F eff wload pln prod(planners weeks work)

* dimensionless
* The effect of work load on planner productivity. If planners have more work they more intensely to complete it.

FRAC W PLANS =F frac w plans(plan ratio)

* dimensionless
* The fraction of work orders for which there is an existing plan in the library.

Library Plans = SINTEG(+Plan reviewed-Obsolescence plans, INT Library Plans,0,:NA:,:NA:,:NA:,:NA:)
* plans
* The library represents the plants memory of previous work. If work has been done before, then planners can reference library for developing new work plans, thus saving time.

D max plans = 26000*5
* plans
* The number of plans that constitutes a full library. At this number of plans there is a plan in the library for 93% of the work orders. This assumes that there is a finite number of things that could be domain the plant.

Obsolescence plans = Library Plans / obsolescence time
* plans/week
* The obsolescence of plans.

obsolescence time = 10*52
* weeks
* The average time before a plan becomes obsolete.

planner productivity = (DR base planner prod W plan*FRAC W PLANS+DR base planner prod WT plan*(1-FRAC W PLANS))*EFF WLOAD PLNNER PROD
* plans/planner/week
* Planner producuvity in terms of plans per week.

planners weeks work = ZIDZ(SMOOTHI(total WO req plans, 4, 10) , ((DR base planner prod W plan * FRAC W PLANS + DR base planner prod WT plan * (1-FRAC W PLANS)) * planners avail plan))
* weeks
* The number of weeks of work the planners have to do.

Plans Wait Eng Rev = SINTEG(Plan created-Plan reviewed,INT Plans Wait Eng Rev,0,:NA:,:NA:,:NA:,:NA:)
* plans
* Plans waiting for being reviewed.

planners avail plan = MAX(planners maint-planners needed to acq mat, 0)
* people
* Planners available to create plans.

DR planners per WO mat req = 2.5/406
* people/work order
* Maintenance staff assigned to planning unplanned WO requiring materials.

plans available = plans completed - Plan created + Plan reviewed
* work orders/week
* Plans available.

total unplanned WO mat req = Unplanned Schd WO Mat Req + Unplanned Unschd WO Mat Req
* work orders
* Total work orders requiring unplanned materials.

```
**********************************************************
    A. Safety ALARA 1(view 30)
**********************************************************

init TD = INITIAL(total defects)

init FOF = INITIAL(forced out frequency)
    * The initial value of forced out frequency.

total FO PCT prob =  Event Occurance Rate[FO] * 100 + EFF EB FO

eff Fort CMF = (Event Occurance Rate[OE] + Event Occurance Rate[IN]) / 4400
    * Core Melts per week
    * This effect is based on the baseline of 4400 events per core melt. There has been one core melt in
      40 years of reactor operation with 110 events per year. Or a chance of 1 / 4400 of an
      event being a core melt. This is the base core melt frequency.

INT Sum Forced Outages = 0.05

INT Total Run Time = 1

core melt frequency est = EFF EB CM * EFF FO CM * eff Fort CMF * EFF TD CM * eff Fort CMF
                        * (1 / operator astuteness) * 1e+006
    * Core Melts per week
    *:SUPPLEMENTARY

DT cap = capacity on-line

DT forced out = EFF Forced Outage

EFF EB CM = F EFFEBCM(frac equip bdwn)

EFF EB FO =F EffEBFO(frac equip bdwn)
    * percentage/week
    * Percentage chance of having an outage per week from broken equipment.

EFF FO CM =  F EFFFOCM(forced out frequency / init FOF)

EFF TD CM = F EFFTDCM(total defects / init TD)
    * dimensionless

FO delay =IF THEN ELSE(Time > 27, 1, 0)

for out funct = IF THEN ELSE(capacity on-line>40 :AND: Time>1000,
            (IF THEN ELSE((100 * RANDOM 0 1()) <=(total FO PCT prob * TIME STEP), 1, 0)
            * FO delay) * (1-Periodic Outage),0)

forced out frequency = Sum Forced Outages / (0.05 + Time)

MORALE =F Morale(Time)
    * dimensionless

operator astuteness = EFF OT FATIGUE OA * MORALE
```

running ave cap = Total Run Time / (0.05 + Time)

Sum Forced Outages = SINTEG(DT forced out, INT Sum Forced Outages,0,:NA:,:NA:,:NA:,:NA:)

Total Run Time = SINTEG(DT cap, INT Total Run Time,0,:NA:,:NA:,:NA:,:NA:)

****

A. Safety ALARA 2(view 32)

****

site emergency funct = IF THEN ELSE(100 * RANDOM 0 1() <= (Event Occurance Rate[OE]
+Event Occurance Rate[IN]) TIME STEP * 100 / 50, 1, 0)
*:SUPPLEMENTARY

start yr reset = IF THEN ELSE(Time<=52, 52, QUANTUM(Time, 52))
* week
* Periodic function for start Yr reset.

minor event funct = IF THEN ELSE(100 * RANDOM 0 1() <= (Event Occurance Rate[OE]
+Event Occurance Rate[IN]) * TIME STEP * 100, 1, 0)
*:SUPPLEMENTARY

eff ManRem um = D MR per unschd WO * Completed unschd WO[U4]

site alert funct = IF THEN ELSE(RANDOM 0 1() <= (Event Occurance Rate[OE]
+Event Occurance Rate[IN]) * TIME STEP * 100 / 10, 1, 0)
*:SUPPLEMENTARY

eff ManRem sm = D MR per schd WO * Completed schd WO[S5]

INT Total ManRem = 9

INT Yr ManRem = 0.01

Chg in ManRem = eff ManRem FO + eff ManRem insp + eff ManRem ops + eff ManRem sm
+ eff ManRem um

eff ManRem FO = DT forced out * D MR per FO

eff ManRem insp = (dinsp W tdwn + dinsp WT tdwn + minsp) * D MR per insp

eff ManRem ops = capacity on-line * D MR percent

D MR per insp = 0.0001

D MR percent = 0.1

D MR per FO = 0.1

D MR per unschd WO = 0.001

MR per week = Total ManRem / (Time + 1)

D MR per schd WO = 0.0005

Total ManRem = SINTEG(Chg in ManRem, INT Total ManRem,0,:NA:,:NA:,:NA:,:NA:)

Yr chg in ManRem = Chg in ManRem

Yr ManRem = SINTEG(Yr chg in ManRem-Yr reset, INT Yr ManRem,0,:NA:,:NA:,:NA:,:NA:)

Yr reset = IF THEN ELSE(time plus>start yr reset :AND: time plus<(start yr reset + TIME STEP),
Yr ManRem / TIME STEP, 0)

****
A. Scheduled Work Order 1(view 7)
****

frac schd WO eq avail W plan = schd plan WO equip avail / (Schd Work Order[S4]+10)
* dimensionless
* Fraction of scheduled work orders in the category of equipment available and having been planned.

frac schd wip W plan = schd plan wip / (Schd Work Order[S5] + 0.1)
* dimensionless
* Fraction of scheduled work orders that is currently being worked on and has been planned.

schd plan wip = MIN(Schd Work Plans Available, Schd Work Order[S5] * D target frac plan)
* work orders
* Scheduled work orders currently being worked that also has been planned.

schd plan WO equip avail = MIN(Schd Work Order[S4] * D target frac plan,
Schd Work Plans Available - schd plan wip)
* work orders
* Scheduled work orders with equipment available and having been planned.

INT Schd Work Plans Available = 100
* work orders
* The initial value of scheduled work plans available.

schd plan WO await equip = Schd Work Plans Available - schd plan wip - schd plan WO equip avail
* work orders
* Scheduled work that have been planned and are awaiting equipment to be taken out of service or put into service for work to proceed.

Schd work plans completed = plans available * frac planning work for schd WO
* work order/week
* The rate at which plans are completed for scheduled work orders; iE. the rate at which work orders are planned and developed.

Schd Work Plans Available = SINTEG(Schd work plans completed-Schd work plans expended
, INT Schd Work Plans Available,0,:NA:,:NA:,:NA:,:NA:)
* work orders
* The number of plans that have been completed for scheduled work and are awaiting exection.

Schd work plans expended = schd work plans used + schd work plans bdwn drop
+ schd work plans forgotten

* work order/week
* The flow of job plans that are used in completing scheduled work orders or become obsolete because the equipment breaks down before the scheduled work can be completed.

D target frac plan = 0.5

* planned work orders/work orders
* The target fraction of work that is to be planned.

****
A. Scheduled Work Order 2(view 8)
****

New planned schd WO mat req = frac schd plan WO mat req * Schd work plans completed

* work orders/week
* The flow (build up) of scheduled and planned work orders that require additional materials (unforeseen material requirements). The additional material requirements are unexpected and may require expediting.

frac schd plan WO mat req = 1 - (SERVICE LEVEL * D utilization)

* dimensionless
* Fraction of scheduled and planned work orders requiring materials to be ordered.

INTPlanned Schd WO Mat Req = 0.06 * 5

* work orders
* Initial scheduled work requiring materials

DR mat acq delay = 0.5

* weeks
* Material Acquisition Delay.

Planned schd WO mat acq = (Planned Schd WO Mat Req / DR mat acq delay)
+WO bdwn PM equip mat req

* work orders/week
* The rate of reduction of scheduled planned work orders that require materials. The outflow is determined by the number of work orders that receive the necessary materials and work orders that become obsolete because the equipment breaks down before the scheduled work can be completed.

Planned Schd WO Mat Req = SINTEG(New planned schd WO mat req-Planned schd WO mat acq
, INT Planned Schd WO Mat Req,0,:NA:,:NA:,:NA:,:NA:)

* work orders
* The number of scheduled and planned work orders that are awaiting materials for completion of work.

WO bdwn PM equip mat req = Planned Schd WO Mat Req / total schd WO waiting TBD
*WO for bdwn PM equip

* work orders/week
* Work orders for brokendown PM equipment requiring materials.

****

A. Scheduled Work Order 3(view 9)

****

frac WO await equip W plan = schd plan WO await equip / (Schd Work Order[S3] + 10)
* dimensionless
* Fraction of scheduled work orders that are awaiting equipment that has been planned.

frac schd WO WTBD avail = SMOOTH(Schd Work Order[S4] / (total schd WO waiting TBD + 10), 5)
* dimensionless
* Fraction of scheduled work orders waiting to be done where the equipment is available.

schd WO RTBD BD = Schd Work Order[S5] + schd WO avail tdwn
* work orders
* All work that either in progress or available to be worked.

schd WO avail tdwn = Schd Work Order[S4] - (Planned Schd WO Mat Req * (Schd Work Order[S4] / (total schd WO waiting TBD+10)))
* work orders
* The number of scheduled work orders that are available to work on. This is equal to the number of work orders for which the equipment is available less the work orders that are awaiting materials.

total schd WO in sys = Schd Work Order[S5] + total schd WO waiting TBD
* work orders
* The total number of work orders that are in some way scheduled.

total schd WO waiting TBD = Schd Work Order[S3] + Schd Work Order[S4]
* work orders
* Total scheduled work that is waiting to be done, includes wo with equipment available and wo waiting equipment.

frac schd WO TBD w plan = (schd plan WO equip avail + schd plan WO await equip) / (total schd WO waiting TBD + 10)
* dimensionless
* The fraction of scheduled work orders awaiting to be done that have been planned.

schd work plans used = Completed schd WO[S5] * frac schd wip W plan
* work orders/week
* The use of plans in completing scheduled work.

schd work plans bdwn drop = WO for bdwn PM equip * frac schd WO TBD w plan
* work orders/week
* Scheduled work that has been planned but is dropped from the backlog of scheduled work to be done because a breakdown requiring unscheduled work supersedes the previously planned work.

schd work plans forgotten = schd WO aw eq forgotten * frac WO await equip W plan
* work orders/week
* Scheduled work orders in the scheduled available to work which is forgotten each week.

****

A. Scheduled Work Order 4(view 10)

****

Completed schd WO[XSched Work Order]=IF THEN ELSE(Schd Work Order[XSched Work Order]
<schd WO comp[XSched Work Order] * TIME STEP,
Schd Work Order[XSched Work Order] / TIME STEP,
schd WO comp[XSched Work Order])

* work orders/week
* Flow of work orders back and forth between Schd WO Awaiting Equipment and Schd WO with Eq Available based on the production needs.

D schd WO memory = 26

* weeks
* Scheduled work order memory. Fraction of work orders forgotten each week. This will depend on how good a system you have for setting priorities and keeping track equipment that is identified as being defective.

New schd WO[S1] = dfct equip req tdwn/DR equip per WO+CA cmplted[MOD]*D schd WO per mod CA
New schd WO[S2] = Completed schd WO[S1]
New schd WO[S3] = Completed schd WO[S2]
New schd WO[S4] = Completed schd WO[S3]
New schd WO[S5] = Completed schd WO[S4]

* work orders/week
* New scheduled work orders awaiting equipment. The flow of new scheduled work orders that are waiting for equipment to become available.

D time to tdwn = 0.5

* weeks
* Target weeks work in progress. The target number of weeks worth of work orders that maintenance want to be working on. Exogenous variable.

EFF ENG WO RT DEF =F EFF eng wo rt def((Completed schd WO[S1] / init completed schd WO[S1]))

* dimensionless

EFF MT WO RT DEF =F Eff Mt wo rt def((Completed schd WO[S2] / init completed schd WO[S2]))

* dimensionless

eff schd work = total schd WO/(Defects ID)

Forget schd WO[S1] = IF THEN ELSE(Schd Work Order[S1]>2 * Completed schd WO[S1],
Schd Work Order[S1] / D eng and mgr forget time, 0)
Forget schd WO[S2] = IF THEN ELSE(Schd Work Order[S2] > 2 * Completed schd WO[S2],
Schd Work Order[S2] / D eng and mgr forget time, 0)
Forget schd WO[S3] = schd WO aw eq forgotten +WO for bdwn PM equip
* (1 - frac schd WO WTBD avail) * eff schd work
Forget schd WO[S4] = eff schd work * SMOOTH(WO for bdwn PM equip
* frac schd WO WTBD avail, 10)
Forget schd WO[S5] = 0

* work orders/week
* Scheduled work orders awaiting equipment not done. The work orders not initiated because either the work is forgotten or the equipment breakdown, requiring unscheduled work which supersedes schd WO.

init completed schd WO[S1] = INITIAL(Completed schd WO[S1])
init completed schd WO[S2] = INITIAL(Completed schd WO[S2])

INT Schd Work Order[S1] = 62.74 * 5
INT Schd Work Order[S2] = 100
INT Schd Work Order[S3] = 62.74 * 5
INT Schd Work Order[S4] = 8.5 * 5
INT Schd Work Order[S5] = 7.03 * 5
* work orders
* The initial value of scheduled work order.

schd WO comp[S1] = eng schd WO rev comp
schd WO comp[S2] = mgr schd WO rev comp
schd WO comp[S3] =(Schd Work Order[S3] / SCHD WAIT TIME by PROD)
- (Schd Work Order[S4] / SCHD RECYCLE TIME)
schd WO comp[S4] = SMOOTH(schd WO avail tdwn, 5) / D time to tdwn
schd WO comp[S5] = normal schd WO completed * human effs on WO comp

SCHD RECYCLE TIME =F schd recycle time(production pressure)
* weeks
* Scheduled recycle time. This is the time equipment will be available before operations takes it back and it returns to the awaiting equipment availability state.

SCHD WAIT TIME by PROD =F schd wait time by prod(production pressure)
* weeks
* Scheduled wait time. This is the time a work order has to wait to be scheduled based on the demand for production versus the actual production being achieved. This graph is based on having a 2 week wait at 100% of desired production.

schd WO aw eq forgotten = Schd Work Order[S3] / D schd WO memory
* work orders/week
* Scheduled work orders awaiting equipment forgotten. The number of work orders in the scheduled available to work which is forgotten each week.

Schd Work Order[XSched Work Order] = SINTEG(+New schd WO[XSched Work Order]
- Completed schd WO[XSched Work Order]
- Forget schd WO[XSched Work Order]
, INT Schd Work Order[XSched Work Order],0,:NA:,:NA:,:NA:,:NA:)

total schd WO = Schd Work Order[S1] + Schd Work Order[S2] + total schd WO in sys
* work orders

D schd WO per mod CA = 4
* work orders/corrective action
* Scheduled work orders per modification corrective action.

****
A. Scheduled Work Order 5(view 11)
****

frac unplnd schd WO mat req = 1 - (SERVICE LEVEL * D utilization)
* dimensionless
* Fraction of scheduled and unplanned work orders requiring materials to be ordered.

INT Unplanned Schd WO Mat Req = 3.09 * 5
* work orders
* The initial value of scheduled work orders unplanned material requirements.

New unplnd schd WO mat req = Completed schd WO[S4] * (1 - frac schd WO eq avail W plan)
* frac unplnd schd WO mat req
* work orders/week
* New scheduled work orders that have unplanned material requirements.

Unplanned Schd WO Mat Req = SINTEG(New unplnd schd WO mat req - Unplnd schd WO mat acq
, INT Unplanned Schd WO Mat Req,0,:NA:,:NA:,:NA:,:NA:)
* work orders
* Scheduled work orders that have unforeseen material requirements.

Unplnd schd WO mat acq = Unplanned Schd WO Mat Req / DR mat acq delay
* work orders/week
* Scheduled work orders that have been unplanned material acquisition.

****
A. Stores(view 23)
****

parts needed = total WO completed * DR ave parts per WO

Parts accptd =deliveries * (1 - frac dfct parts rtrnd)
* parts/week
* Parts accepted.

Defective Part Inventory = SINTEG(Dfcts accptd - New dfcts parts, INT Defective Part Inventory,0
,:NA:,:NA:,:NA:,:NA:)
* defective parts
* Defective parts that are in the parts inventory.

deliveries = bud maint parts / DR dollars per part
* dimensionless
* Raw material deliveries.

New dfcts parts = IF THEN ELSE(Time > 25, Parts consumed * pct inventory dfctv / 100, 1400)
* defective parts/week
* New defects resulting from defective parts that are installed in equipment.

Dollar deliveries = Parts accptd * DR dollars per part
* dollars/week
* Parts deliveries measured in dollars.

Parts consumed =IF THEN ELSE(Stores Inventory<parts needed * TIME STEP, Stores Inventory
/ TIME STEP, parts needed)
* parts/week
* Parts used in completing work orders.

frac parts dfct at delvry = Event Occurance Rate[DR]
* dimensionless
* Fraction of parts delivered that are defective.

INT Defective Part Inventory = Stores Inventory * frac parts dfct at delvry
* (1 - FRAC RTRND GIVEN DFCT)
* defective parts
* The initial value of Defective inventory.

INT Stores Dollars = Stores Inventory * DR dollars per part
* dollars
* The initial value of Stores Dollars.

INT Stores Inventory = 60000 * 5
* parts
* The initial value of stores inventory.

DR dollars per part = (4.2 / (52 * 374 * DR ave parts per WO))
* million dollars/part
* Average cost per part. Current set up takes average parts per work order into account. If you assume that the more parts per work order implies ordering smaller parts---gaskets, bolts, nuts, wires, bearings, grease, etc. --where as ordering fewer parts per work order implies ordering large parts-- motors, valves, grar boxes, pumps, etc--, more parts per work order implies a smaller average cost per part.

ave dollars per part = ZIDZ(Stores Dollars , Stores Inventory)
* dollars/part
* Average cost per part in inventory.

DR ave parts per WO = 5
* parts/work order
* Average parts per work order.

Dfcts accptd = Parts accptd * frac dfct parts accptd
* defective parts/week
* New defective parts that are accidentally accepted.

frac dfct parts accptd = frac parts dfct at delvry * (1 - FRAC RTRND GIVEN DFCT)
* dimensionless
* The fraction of parts that are accepted.

frac dfct parts rtrnd = FRAC RTRND GIVEN DFCT * frac parts dfct at delvry
* dimensionless
* The fraction of incoming parts that are returned.

Maint materials cost = Parts consumed * ave dollars per part
* Parts consumption measured in dollars.

pct inventory dfctv =100 * MIN(ZIDZ(Defective Part Inventory , Stores Inventory),1)
* percentage
* Percentage of parts that are defective.

DR replacement investment = 444
* million dollars
* Replacement investment

SERVICE LEVEL = F Service Level(stores ratio)
* dimensionless
* Probability of normally stocked part currently being in inventory.

stores inv per ERV = 100 * (Stores Dollars / DR replacement investment)
* dimensionless
* Stores inventory per estimated replacement investment.

Stores Dollars = SINTEG(Dollar deliveries-Maint materials cost
, INT Stores Dollars,0,:NA:,:NA:,:NA:,:NA:)
* million dollars
* Parts inventory measured in dollars.

Stores Inventory = SINTEG(Parts accptd - Parts consumed,
INT Stores Inventory,0,:NA:,:NA:,:NA:,:NA:)
* parts
* The number of total parts in the storeroom.

stores ratio = stores inv per ERV / D target inventory as PCT ERV
* dimensionless

D target inventory as PCT ERV = 1.09
* dimensionless
* This is the target for stores investment as a percent of estimated replacement investment that creates the proper service level in stores.

****
A. Unscheduled Work Order 1(view 13)
****

frac planned unschd WO req mat = 1 - (SERVICE LEVEL * D utilization)
* dimensionless
* The fraction of unscheduled, planned work orders that require additional materials that must be ordered; iE. not currently in warehouse stock.

frac unschd wip W plan = unschd plan wip / (Unschd Work Order[U4] + 10)
* dimensionless
* The fraction of unscheduled work orders that have a plan.

frac unschd WO pfunc W plan = unschd plan WO pfunc / (Unschd Work Order[U3] + 10)
* dimensionless
* The fraction of unscheduled work orders on partially functional equipment that have a plan.

INT Planned Unschd WO Mat Req = 2.7
* work orders
* The initial value of unscheduled planned work orders requiring materials.

INT Unschd Work Plans Available =10
* work orders
* The initial value of unscheduled work plans available.

New planned unschd WO mat req = Unschd work plans completed * frac planned unschd WO req mat
* work orders/week
* The flow of new unscheduled , planned work orders that requiring materials.

Unschd work plans used = Completed unschd WO[U4] * frac unschd wip W plan
* work orders/week
* Planned unscheduled work orders that are consumed in the process of completing unscheduled work.

unschd plan wip = MIN(Unschd Work Order[U4] * D target frac plan, Unschd Work Plans Available)
* work orders
* Unscheduled work orders currently being worked on that have a plan.

Planned unschd WO mat acq = Planned Unschd WO Mat Req / DR mat acq delay
* work orders/week
* The flow unscheduled, planned work orders that have received the additional materials.

unschd plan WO pfunc = Unschd Work Plans Available - unschd plan wip
* work orders
* Unscheduled work orders that are partially functional that have a plan.

Planned Unschd WO Mat Req = SINTEG(New planned unschd WO mat req
-Planned unschd WO mat acq
, INT Planned Unschd WO Mat Req,0,:NA:,:NA:,:NA:,:NA:)
* work orders
* The number of unscheduled, planned work orders that are waiting for additional materials for work to begin.

Unschd Work Plans Available = SINTEG(+Unschd work plans completed-Unschd work plans used
, INT Unschd Work Plans Available,0,:NA:,:NA:,:NA:,:NA:)
* work orders
* Unscheduled work orders with plans that are available to be worked.

Unschd work plans completed = plans available * (1 - frac planning work for schd WO)
* work orders/week
* The completion of plans for unscheduled work orders.

****
A. Unscheduled Work Order 2(view 14)
****

Completed unschd WO[U1] = IF THEN ELSE(Time>0, eng unschd WO rev comp, 1250)
Completed unschd WO[U2] = IF THEN ELSE(Time>0, mgr unschd WO rev comp, 1250)
Completed unschd WO[U3] = (Unschd Work Order[U3] - Planned Unschd WO Mat Req) /
DR unschd backlog time
Completed unschd WO[U4] = normal unschd WO completed * human effs on WO comp
* work orders/week

D eng and mgr forget time = 12

DR unschd backlog time = 1
* weeks
* Unscheduled backlog time. This is the time between noticing a piece of equipment begins to fail and the time that it is available to work on.

EFF UW ERT DEF =F EFF uw Ert Def((Completed unschd WO[U1] / init completed unschd WO[U1]))
* dimensionless

EFF UWO MRT DEF =F EFFuwoMrtdef(Completed unschd WO[U2] / init completed unschd WO[U2])
* dimensionless

Forget unschd WO[U1] = IF THEN ELSE(Unschd Work Order[U1] > 2 * Completed unschd WO[U1],
Unschd Work Order[U1] / D eng and mgr forget time, 0)
Forget unschd WO[U2] = IF THEN ELSE(Unschd Work Order[U2] > 2 * Completed unschd WO[U2],
Unschd Work Order[U2] / D eng and mgr forget time, 0)
Forget unschd WO[U3] = 0
Forget unschd WO[U4] = 0

init completed unschd WO[U1] = INITIAL(Completed unschd WO[U1])
init completed unschd WO[U2] = INITIAL(Completed unschd WO[U2])

INT Unschd Work Order[U1] = 359.13 * 5
INT Unschd Work Order[U2] = 1500
INT Unschd Work Order[U3] = 1500
INT Unschd Work Order[U4] = 353.63 * 5
* work orders
* The initial value of unscheduled work orders.

New unschd WO[U1] = (on-line bdwns + tagged PM equip bdwns) / DR equip per WO
New unschd WO[U2] =Completed unschd WO[U1]
New unschd WO[U3] = Completed unschd WO[U2]
New unschd WO[U4] = Completed unschd WO[U3]
* work orders/week
* The flow of new unscheduled work orders.

unschd WO part func eq = total unschd WO - Unschd Work Order[U4]
*:SUPPLEMENTARY

Unschd Work Order[XUnschd Work Order] = SINTEG(+New unschd WO[XUnschd Work Order]
-Completed unschd WO[XUnschd Work Order]-
Forget unschd WO[XUnschd Work Order]
, INT Unschd Work Order[XUnschd Work Order],0,:NA:,:NA:,:NA:,:NA:)
* work orders

****

A. Unscheduled Work Order 3(view 15)

****

total unschd WO =Unschd Work Order[U1] + Unschd Work Order[U2] + Unschd Work Order[U3] +
Unschd Work Order[U4]
* work orders
* Total number of unscheduled work orders currently open.

frac planning work for schd WO = schd WO req plans/total WO req plans
* dimensionless
* The fraction of planning work the planner performs on scheduled work orders.

frac unplnd unschd WO mat req = 1 - (D utilization * SERVICE LEVEL)
* dimensionless
* The fraction of unscheduled , unplanned work orders that require additional materials to be ordered; iE. parts not currently in warehouse stocks.

frac schd WO = ZIDZ(Completed schd WO[S5] , total WO completed)
* dimensionless
* Fraction of all work orders completed that are scheduled wo.
*:SUPPLEMENTARY

INT Unplanned Unschd WO Mat Req = 70.5 * 5
* work orders
* The initial value of unscheduled work orders unplanned material requirements.

New unplnd unschd WO mat req = Completed unschd WO[U3] * frac unplnd unschd WO mat req
* (1 - frac unschd WO pfunc W plan)
* work orders/week
* New unscheduled work orders unplanned material requirements.

schd WO req plans = MAX(total schd WO * D target frac plan - Schd Work Plans Available, 1)
* work orders
* Scheduled work orders requiring plans.
total WO completed = Completed schd WO[S5] + Completed unschd WO[U4]
* work orders/week
* The total number of work orders completed per week, both scheduled and unscheduled.

total WO req plans = schd WO req plans + unschd WO req plans
* work orders
* Total work orders requiring plans.

unschd WO req plans = MAX((total unschd WO - Unschd Work Order[U1] - Unschd Work Order[U2])
* D target frac plan - Unschd Work Plans Available, 1)

Unplnd unschd WO mat acq = Unplanned Unschd WO Mat Req / DR mat acq delay
* work orders/week
* Unscheduled, planned work orders for which the additional materials arrive.

Unplanned Unschd WO Mat Req = SINTEG(New unplnd unschd WO mat req
-Unplnd unschd WO mat acq
, INT Unplanned Unschd WO Mat Req,0,:NA:,:NA:,:NA:,:NA:)
* work orders
* Unscheduled, unplanned work orders that are waiting for materials.

D utilization = 0.7
* dimensionless
* The fraction of materials that come from plant stores. Exogenous variable. This variable represents the fraction of parts used in the plant that is carried by the plant warehouse.

B. Social Sector (view 33 - 36)

****

B. Interest group 1(view 35)

****

INT IG Lawsuits = 2
* suits
* The initial value of interest group lawsuits.

DR ave time to dismiss = 26
* weeks
* Average time to dismiss.

DR ave time to settle = 2 * 52
* weeks
* Average time to settle.

DR ave trial duration = 6 * 52
* weeks
* Average trial duration.

Dismissal rate = I G Lawsuits / DR ave time to dismiss
* suits/week
* Dismissal rate.

Out court settle rate = I G Lawsuits / DR ave time to settle
* specs/week
* Out of court settlement rate.

Suit filing rate = social concerns * (EFF BREAKDWN P2 + EFF OPS + EFF BREAKDWN)
* suits/week
* Suit filling rate.

Trial resolution rate = I G Lawsuits / DR ave trial duration
* suits/week
* Trial resolution rate.

****

B. Interest group 2(view 36)

****

EFF PI PO =F EFFPIPO(Effective Anti Nuclear Campaigns / INT Effective Anti N Campaigns)
* dimensionless
* Effect of public interest on public concern.

EFF NPO PI =F EFFPOPI(Public Opposition[NA])
* dimensionless

EFF LPO PI =F EFFLPOLPI(Public Opposition[LO])
* dimensionless

INT Anti Nuclear Campaigns = 0.84
* campaigns
* The initial value of anti nuclear campaigns.

INT Effective Anti N Campaigns = 0.55
* campaigns
* The initial value of effective anti nuclear campaigns.

Anti Nuclear Campaigns = SINTEG(Campaign initation rate-Failure rate
-Implementation rate, INT Anti Nuclear Campaigns,0,:NA:,:NA:,:NA:,:NA:)
* campaigns
* Anti-nuclear campaigns.

D ave campaign effect life = 4
* weeks
* Average campaign effective life.

D ave campaign development time = 12
* weeks
* Average campaigns development time.

Campaign initation rate = social concerns * (EFF BREAKDWN P2 + EFF OPS / 20
+ EFF BREAKDWN / 20)
* campaigns/week
* Campaign initation rate.

EFF BREAKDWN =F Eff Breakdwn(frac equip bdwn + EFF Forced Outage)
* actions/week
*. Effect breakdowns.

EFF BREAKDWN P2 =F Eff Breakdwn P2(t bdwns P2)
* actions/week
* Effect breakdowns.

EFF OPS =F Eff Ops(capacity on-line + (95 * Periodic Outage))
* actions/week
* Effect operations.

Effect fading = Effective Anti Nuclear Campaigns / D ave campaign effect life
* campaigns/week
* Effective fading.

Effective Anti Nuclear Campaigns = SINTEG(+Implementation rate-Effect fading
, INT Effective Anti N Campaigns,0,:NA:,:NA:,:NA:,:NA:)
* campaigns
* Effective anti-nuclear campaigns.

EFF PI LM =F EFFPILM(Effective Anti Nuclear Campaigns)
* dimensionless
* Effect of public interest on lawmakers.

EFF PI M =F EffPIM(Effective Anti Nuclear Campaigns + I G Lawsuits)
* dimensionless

EFF PI NRC =F EFFPINRC(Effective Anti Nuclear Campaigns + I G Lawsuits)
* dimensionless
* Effect of public interest on public concern.

EFF PI PUC =F EFFPIPUC(Effective Anti Nuclear Campaigns)
* dimensionless
* Effect of public interest on lawsuits.

Failure rate = Anti Nuclear Campaigns * D frac campaign failed / D ave campaign development time
* campaigns/week
* Failure rate.

D frac campaign failed = 0.5
* dimensionless
* Fraction campaigns failed.

I G Lawsuits = SINTEG(+Suit filing rate-Dismissal rate-Out court settle rate -Trial resolution rate, INT IG Lawsuits,0,:NA:,:NA:,:NA:,:NA:)
* suits
* Interest group lawsuits.

Implementation rate = Anti Nuclear Campaigns / D ave campaign development time
* campaigns/week
* Implementation rate.

social concerns = EFF CL PI * EFF LPO PI *EFF NPO PI

****

B. Media coverage(view 34)

****

start plant force out = IF THEN ELSE(Time=0, 0,QUANTUM(Time, TIME STEP))
* Periodic function for plant force out.

init EMR = INITIAL(Effective Media Reports)
* The initial value of effective media reports.

plant force out = IF THEN ELSE(time plus>start plant force out :AND: time plus<(start plant force out + TIME STEP), 1/TIME STEP, 0) * for out funct
* breakdowns/week
* Plant breakdowns.

INT Effective Media Reports = 2
* articles
* The initial value of effective media reports.

INT Event Reports = 0
* articles
* The initial value of event reports.

INT Followup Reports = 0.5
* articles
* The initial value of follow up reports.

INT Operating Reports = 0.3
* articles
* The initial value of operating reports.

D ave rpt effect life = 4
* weeks
* Average report effective life.

Effect rpt fading =Effective Media Reports / D ave rpt effect life
* articles/week
* Effective reporting fading.

Effective Media Reports = SINTEG(+Event rpt dissimination+Followup rpt dissimination
+Operational rpt dissimination-Effect rpt fading,
INT Effective Media Reports,0,:NA:,:NA:,:NA:,:NA:)
* articles
* Effective media reports.

EFF M LM =F EFFMLM(Effective Media Reports)
* dimensionless
* Effect of media on lawmakers.

EFF M NRC = F EFFMNRC(Effective Media Reports)
* dimensionless
* Effect of media on public concern.

EFF M PO =F EFFMPO(Effective Media Reports / init EMR)
* dimensionless
* The media transmits information deemed to be of public interest to the general public. This variable represents the impact of media articles upon the public's concern over nuclear power.

Event rpt dissimination = Event Reports / D evt rpt spread time
* articles
* Operations report dissemination.

Event rpting rate = PLANT BREAKDWNS P2 + (plant force out / 200) * 0
* articles/week
* Event reporting rate.

event switch = 0
* dimensionless
* 1 initiates major event at other nuclear facility in week 156.
0 event off.

Event Reports = SINTEG(+Event rpting rate-Event rpt dissimination
, INT Event Reports,0,:NA:,:NA:,:NA:,:NA:)
* articles
* Event reports. The development of background reports for media articles on major plant events.

D evt rpt spread time = 2
* weeks
* The time for information in media article to disseminate throughout the country.

Follow rpting rate =social multiplier * (Event rpt dissimination + Operational rpt dissimination)
* articles/week
* Followup reporting rate.

Followup rpt dissimination = FollowupReports/D fwup rpt spread time
* articles/week
* Follow up reporting dissemination.

FollowupReports = SINTEG(Follow rpting rate-Followup rpt dissimination
, INT Followup Reports,0,:NA:,:NA:,:NA:,:NA:)
* articles
* Follow up report.

D fwup rpt spread time = 1.5
* weeks
* The time for follow up reports to disseminate across the country.

D op rpt spread time = 3
* weeks
* Time for operations articles to disseminate throughout country.

Operating rpting rate = (OPERATING CONDITIONS +dfct operating reports) * EFF PI M
* articles/week
* Operating reporting rate.

Operating Reports = SINTEG(Operating rpting rate-Operational rpt dissimination
, INT Operating Reports,0,:NA:,:NA:,:NA:,:NA:)
* articles
* Operating reports.

OPERATING CONDITIONS =F Operating Conditions(capacity on-line + (100 * Periodic Outage))
* articles/week
* Operating news. Represents media attention toward a nuclear plant--assuming such attention is a function of on-line capacity of plant performance.

Operational rpt dissimination = Operating Reports /D op rpt spread time
* articles/week
* Operations report dissemination.

PLANT BREAKDWNS P2 =F Plant breakdwns P2(t bdwns P2)
* breakdowns/week
* Plant breakdowns.

social multiplier = EFF CL M * EFF LPO M * EFF NPO M
* dimensionless
* Combined impact of social concerns on the media's efforts for followup reports.

t bdwns P2 = 0 + (STEP(10000 / 13400, 156) - STEP(10000 / 13400, 166)) * event switch

****
B. Public concern 1(view 32)
****

bound PO[NA] = MAX(MIN(ind pub opp[NA], 90), 20) bound PO[LO] = MAX(MIN(ind pub opp[LO], 95), 5)

Chg pub opp[X Public Concern] = (bound PO[X Public Concern] - Public Opposition[X Public Concern]) / time to chg opp[X Public Concern]

D ave desensitization[X Public Concern] = 520, 520
* weeks

EFF LPO CUS SAT =F EFFPOCussat(Public Opposition[LO])
* dimensionless
* Effect of local public opposition on customer satisfaction.

EFF LPO GW = F EFFLPOGW(Public Opposition[LO])

EFF LPO M =F EFFLPOM(Public Opposition[LO])
* dimensionless

EFF LPO PER SAF =F EFFLPOPerSaf(Public Opposition[LO])
* dimensionless

EFF LPO StRISK =F EFFLPOStRisk(Public Opposition[LO])

EFF NPO LM =F EFFPOLM(Public Opposition[NA])
* dimensionless
* Effect of public concern on lawmakers.

EFF NPO LPO =F EFFPOLPO(Public Opposition[NA])
* dimensionless

EFF NPO M = F EFFPOM(Public Opposition[NA])
* dimensionless
* Effect of public concern on media.

EFF NPO PER SAF =F EFFPOPerSaf(Public Opposition[NA])
* dimensionless
* This is the effect that Nat Public Opposition has on the perceived safety of nuclear plants by the financial community.

EFF NPO StRISK =F EFFPOStRisk(Public Opposition[NA])
* dimensionless
* Effect of public concern on stock risk. This factor on risk represents the latent fear of individuals to buy the stock thus increasing the risk factor and driving stock price down. It can represents other factors too such as the fact that as public concern grows more stockholders become anti-nuke possible demanding that the company diversify out of the nuclear business.

EFF OPS LPO =F EffOpsLPO((capacity on-line + (Periodic Outage * 80)) / (EFF Forced Outage + 1))
* dimensionless

EFF OPS NPO =F EFFUOpsPO((capacity on-line / 100) + (Periodic Outage * 0.8))
* dimensionless
* Effect of Utility Public Relation on Public Concern. Utilities spend much time and resources trying to assuage the public fears over nuclear power. This variable represents the impact of those actions on public concern.

EFF UT GOODWILL LPO =F EffUtGoodwillLPO(Utility Goodwill/ init UG)
* dimensionless

Fading pub opp[X Public Concern] = Public Opposition[X Public Concern] /
D ave desensitization[X Public Concern]

ind pub opp[X Public Concern] = Public Opposition[X Public Concern]
* net effect[X Public Concern]

init UG = INITIAL(Utility Goodwill)
* The initial value of utility goodwill.

INT Public Opposition[X Public Concern] = 20, 15

net effect[NA] = EFF PI PO * EFF M PO * EFF OPS NPO * EFF NRC PO * EFF SALP NPO
net effect[LO] = EFF NRC PO * EFF M PO * EFF OPS LPO * EFF PI PO * EFF NPO LPO
* EFF UT GOODWILL LPO * EFF SALP LPO
* dimensionless
* Various factors influence the public's concern over nuclear power. This variable calculates the net effect of all variables within this model acting on public concern.

Public Opposition[X Public Concern] = SINTEG(Chg pub opp[X Public Concern]
- Fading pub opp[X Public Concern],
INT Public Opposition[X Public Concern],0,:NA:,:NA:,:NA:,:NA:)
* concerns

time to chg opp[NA] = 6 * Public Opposition[NA] / ind pub opp[NA]
time to chg opp[LO] = 4 * Public Opposition[LO] / ind pub opp[LO]
* weeks

****
B. Public concern 2(view 33)
****

INT Utility Goodwill = 1

DR dollar on education = 0.02
* million dollars/week
* Money spent on public education which translates into goodwill.

EFF CUS SAT GW = F EffCussatGW(customer satisfaction)

EFF LOC ED GW = F EffLOCEdGW(DR dollar on education / 0.05)

GW change = (ind goodwill - Utility Goodwill) / GW change time

GW change time = 52 * ind goodwill / Utility Goodwill

ind goodwill = EFF CUS SAT GW * EFF LOC ED GW * EFF LPO GW

Utility Goodwill = SINTEG(GW change, INT Utility Goodwill,0,:NA:,:NA:,:NA:,:NA:)

C. Government Sector (view 37 - 41)

****

C. Congress concern(view 40)

****

ind concerned lmkrs = Concerned Lawmakers * net effect on lmkrs
* lawmakers/week
* Indicated concerned lawmakers.

DR lawmakers = 535

INT Concerned Lmkrs = 0.1 * DR lawmakers
* people
* Concerned lawmakers.

INT EFFForcOut = 0

D ave lmkr memory = 20

ind lmkr limits = MAX(MIN(535, ind concerned lmkrs), 40)
* lawmakers
* Upper and lower bounds for the number of concerned lawmakers (0 to 535)

Changing opposition = (ind lmkr limits - Concerned Lawmakers) / lmkr adj time
* lawmakers/week
* The rate at which congressional opposition to nuclear power changes in the U.S.House and Senate.

Concerned Lawmakers = SINTEG(Changing opposition-Fading lmkr concern
, INT Concerned Lmkrs,0,:NA:,:NA:,:NA:,:NA:)
* people
* The number of lawmakers in congress who are significantly concerned over nuclear power plant safety.

EFF BDWN LM = F EFFBdwnLM(EFF Forced Outage+frac equip bdwn)
* dimensionless
* Effect plant breakdowns on lawmakers.

EFF BDWN LM P2 =F EFFBdwnLM P2(t bdwns P2)
* dimensionless
* Effect plant breakdowns lawmakers.

EFF CL M =F EFFCLM(Concerned Lawmakers)
* dimensionless

EFF CL NRC =F EFFCLNRC(Concerned Lawmakers)
* dimensionless
* Effect of concerned lawmakers on NRC concern.

EFF CL PI =F EFFCLPI(Concerned Lawmakers)
* dimensionless

EFF Forced Outage = SINTEG(+PB eff rate-Fade PB eff, INT EFFForcOut,0,:NA:,:NA:,:NA:,:NA:)
* dimensionless
* Effect of forced outage. Effect from forced outage is a stock to represent the time to buildup of the effect on other sectors and the time to cool off. It represents the time to determune the cause of S/D and resume start up. An average length of S/D per forced outage is used.

EFF LOB LM = F EFFLOBLM(max bud lobby)

Fade PB eff = EFF Forced Outage / fade time

fade time = MAX((0.25 * RANDOM NORMAL()+1.5), 0)

Fading lmkr concern = Concerned Lawmakers / D ave lmkr memory
* lawmakers/week
* Number of lawmakers whose fear of nuclear safety dissipates.

lmkr adj time = 6 * Concerned Lawmakers / ind concerned lmkrs
* weeks
* The average time to shift congressional support from one position to another. 3 months.

net effect on lmkrs = EFF BDWN LM * EFF M LM * EFF NPO LM * EFF PI LM * EFF BDWN LM P2 *EFF LOB LM* EFF SALP NPO
* dimensionless
* A variety of factors affect a congress person's position regarding nuclear power. This variable calculates the net effect of various factors operating on congress in relation to nuclear power.

PB eff rate = plant force out - 0.5

****
C. NRC 1(view 37)
****

INT NRC Inspection Backlog = DR base insp rate
* inspections
* The initial value of NRC inspection backlog.

adjusted insp rate = ind insp rate * social effect NRC * EFF CL NRC
* inspections/week
* Adjusted inspection rate.

DR base insp rate = 3 / 52
* inspections/week
* Base level of inspections per plant per week.

EFF BDWN NRC IN =F EFFBdwnNRCIn(frac equip bdwn)
* inspections/week
* Effect of events on NRC. The number of additional inspections initiated because of consistent equipment breakdowns.

EFF BDWN NRC IN 2 =F EFFBdwnNRCIn 2(t bdwns P2)
* inspections/week
* Effect of events on NRC. The number of additional inspections initiated because of consistent equipment breakdowns.

EFF OPS NRC IN =F EFFOpsNRCIn(capacity on-line + (100 * Periodic Outage))
* inspections/week
* Effect of informants on NRC. The number of inspections added because of poor operating performance.

ind insp rate = DR base insp rate + special requirement for inquiry
* inspections/week
* Indicated inspection rate.

Insp planning = adjusted insp rate
* inspections/week

inspection ratio = Plant inspecting / DR base insp rate
* dimensionless

NRC evilness = 0
* 0.15 is nice effect. Run with and without of regs within info sector.

NRC Inspection Backlog = SINTEG(Insp planning-Plant inspecting
, INT NRC Inspection Backlog,0,:NA:,:NA:,:NA:,:NA:)
* inspections
* Inspections backlog.

Plant inspecting = NRC Inspection Backlog / DR time to insp
* inspections/week

social effect NRC = EFF M NRC * EFF PI NRC

special requirement for inquiry = (EFF BDWN NRC IN + EFF OPS NRC IN + EFF BDWN NRC IN 2
+ EFF SITE ALAND EMERG NRC INS) * (1 + NRC evilness)
* inspections/week
* Special requirement for inquiry. Events and informants at plants that create added incentives to inspect.

DR time to insp = 4
* weeks
* Time to inspect

****

C. NRC 2(view 38)

****

EFF NRC REP MDINSP =F EFFNRCrepml(NRC Reports in Progress / INT NRC Reports in Progress)
* dimensionless
* Effect of NRC reports on mandatory and discretionary inspections. This is a multiplier to increase inspections based on reports.

EFF NRC INV MGT ENG =F EFFNRCinvMGTENG(Investigation initiated / init II)
* dimensionless
* As investigations increase engineers and managers are siphoned off for working with the NRC for answering questions, etc. They are taken from the maintenance staff.

init II = INITIAL(Investigation initiated)

EFF NRC INV MINSP =F EFFNRCInvmInsp(NRC Investigation in Progress /
INT NRC Investigation in Progress)
* dimensionless

INT NRC Investigation in Progress = 10
* pages/year
* The initial value of NRC investigation in progress.

INT NRC Reports in Progress = 16
* reports
* The initial value of NRC reports in progress.

DR ave no reports per res proj = 1
* reports/research project
* Average number of reports per research project.

DR ave res proj duration = 1 * 52
* weeks
* Average NRC research project duration.

DR ave time to publish report = 1 * 52
* weeks
* Average time to publish report.

desired NRC research = INITIAL(NRC Investigation in Progress)

EFF BDWN NRC INV =F EFFBdwnNRCInv(frac equip bdwn)
* dimensionless
* Effect breakdowns NRC investigation

EFF BDWN NRC INV P2 =F EFFBdwnNRCInv P2(t bdwns P2)
* dimensionless
* Effect breakdown NRC investigation
*:SUPPLEMENTARY

EFF BDWN NRC INV P2 2 =F EFFBdwnNRCInv P2 2(t bdwns P2)
* dimensionless
* Effect breakdowns NRC investigation.

EFF OPS NRC INV =F EffOpsNRCInv(capacity on-line + (100 * Periodic Outage))
* dimensionless
* Effect operations NRC inventory.

ind NRC invest IP = EFF BDWN NRC INV * EFF BDWN NRC INV P2 2 * EFF OPS NRC INV
* inspection ratio * desired NRC research
* investigations
* Indicated NRC investigation in progress.

Investigation completed = NRC Investigation in Progress / DR ave res proj duration
* investigations/week
* Investigations completed.

Investigation initiated = (ind NRC invest IP - NRC Investigation in Progress) / D response time
* investigations / week
* Investigations initiated.

NRC Investigation in Progress = INTEG(+Investigation initiated
-Investigation completed, INT NRC Investigation in Progress)
* pages/year
* NRC processed information. Before initiating any action the NRC performs various investigations and studies. This level provides and indication of the amount of research being undertaken.

NRC Reports in Progress = INTEG(NRC reports initiated-Reports completed
, INT NRC Reports in Progress)
* reports
* NRC reports in progress.

NRC reports initiated = DR ave no reports per res proj * Investigation completed
* reports/week
* NRC reports initiated.

Reports completed = NRC Reports in Progress / DR ave time to publish report
* reports/week
* Reports completed.

D response time = 3 * 4
* weeks
* 3 months = 4 week/month

****
C. NRC 3(view 39)
****

Abandoning regulation effort = NRC Regulation in Development / DR ave life of unsuccessful reg efforts
+ regs abandoned from NEI effort
* parts/Month
* Discarding.

EFF NRC MINSP = F EFFNRCminsp(Regulations on Books / INT Regulations on Books)

EFF NRC REGD MDINSP =F EFFNRCRDDIMI(NRC Regulation in Development /
INT NRC Regulation in Development)
* dimensionless
* Effect of NRC regulations in development on desired discretionary inspections and mandatory inspections.

REPORT RATIO =F Report Ratio(NRC Reports in Progress / INT NRC Reports in Progress)
* dimensionless

INT NRC Regulation in Development = 0.5
* pages regulations
* The initial value of NRC regulation in development.

INT Regulations on Books = 3.8
* thousands pages regulations
* The initial value of regulations on books.

DR ave life of unsuccessful reg efforts = 2 * 52
* weeks
* Average life of unsuccessful regulatory efforts.

DR ave regulations sought per report = 0.1
* statute per NRC report
* Average regulations sought per report.

DR Discarding regulation = Regulations on Books / 800
* pages/week
* Discarding regulations. Change from /520 to /800.

EFF NRC PO =F EFFGAPO(regulation ratio * inspection ratio)
* dimensionless
* Effect of government action on public concern. Government action may heighten or lessen public fears.

Enacting regulation = NRC Regulation in Development / DR time to enact regulation
* pages regulations/week
* Enacting regulation.

Initiating regulation = REPORT RATIO * DR ave regulations sought per report * Reports completed
* pages regulations/week
* Initiating regulation.

```
NRC Regulation in Development = SINTEG(+Initiating regulation
                                 -Abandoning regulation effort-Enacting regulation,
                                 INT NRC Regulation in Development,0,:NA:,:NA:,:NA:,:NA:)
```
* pages regulations
* NRC regulations in development.

regulation ratio = Regulations on Books /SMOOTH3(Regulations on Books, 26)

```
Regulations on Books = SINTEG(+Enacting regulation-DR Discarding regulation
                       , INT Regulations on Books,0,:NA:,:NA:,:NA:,:NA:)
```
* thousands pages regulations
* Regulations on books.

DR time to enact regulation = 1 * 52
* weeks
* Time to enact regulation.

****

C. SALP(view 41)

****

init MRPW = INITIAL(MR per week)

```
PLANT OPERATIONS = F Plant Operations(running ave cap * operator astuteness
                   * INT Event Occurance Rate[OE] / Event Occurance Rate[OE]
                   * INT Event Occurance Rate[IN] / Event Occurance Rate[IN])
```

init AQS = INITIAL(ave qual specs)

INT SALP = 2.5
* The initial value of SALP.

Chg SALP = (SALP bounds - SALP) / time to chg SALP

cur ind SALP = (ENGINEERING + MAINTENANCE +PLANT OPERATIONS + SUPPORT) / 4

EFF REP ANALYSIS RATIO SALP = F EFF rep analysis ratio SALP(report analysis ratio)

EFF SALP INFO =F EFF SALP info(SALP)

ENGINEERING = F Engineering(IF THEN ELSE(eng workload<0.6, 0.6 * init AQS / ave qual specs, eng workload * init AQS / ave qual specs))

MAINTENANCE = F Maintenance((1 -frac equip bdwn) * running ave cap / 100)

SALP = SINTEG(Chg SALP, INT SALP,0,:NA:,:NA:,:NA:,:NA:)
* dimensionless
* Safety assessment and licensing procedure. This is the rating 1-4, 1 being best of the operations of the nuclear plant.

SALP bounds = MIN(MAX(cur ind SALP, 1), 4)

SUPPORT = F Support(IF THEN ELSE(mgr workload<0.4, 0.4 * EFF REP ANALYSIS RATIO SALP * MR per week /init MRPW, mgr workload * EFF REP ANALYSIS RATIO SALP * MR per week / init MRPW))

time to chg SALP = 52 * cur ind SALP / SALP

D. Information Sector (view 42 - 58)

****

D. Corrective action 1(view 51)

****

INT CA Waiting for Assignment = 35
* corrective action
* The initial value of CA Waiting for Assignment.

adj time to assign CA = DR time to assign CA * info mgr unavail ratio * info eng unavail ratio
* weeks
* Time it takes for a manager to assign CA, adjusted for manager availability.

D assign eng unavail lim = 3
* dimensionless
* Maximum value of manager unavailability allowed. If it becomes greater than this value, CAs are abandoned.

D assign mgr unavail lim = 2
* dimensionless
* Maximum value of manager unavailability allowed. If it becomes greater than this value, CAs are abandoned.

CA abandon = IF THEN ELSE((info mgr unavail ratio>D assign mgr unavail lim):OR:
(info eng unavail ratio>D assign eng unavail lim), CA Waiting for Assignment
* D frac CA abandon, 0)
* corrective action/week
* CA abandoned because managers are unavailable to assign them or because the manager feels that engineers are too busy with other work.

CA assignment = CA Waiting for Assignment / adj time to assign CA
* corrective action/week
* CA assignment to the correct groups.

CA Waiting for Assignment = SINTEG(+New CA waiting-CA abandon-CA assignment, INT CA Waiting for Assignment,0,:NA:,:NA:,:NA:,:NA:)
* corrective action
* Corrective actions waiting to be assigned to correct groups that will perform the actions. Some may be lost if time delays increase too much.

D frac CA abandon = 0.2
* dimensionless
* Fraction of CA abandoned when managers decide to begin to abandon CAs.

D frac evals need mult CA = 0.2
* corrective action/evaluations
* Fraction of evaluations that need multiple corrective actions to solve the problem.

D frac of evals need CA = 0.75
* corrective action/evaluations
* Fraction of validated evaluations that require corrective action within the utility.

New CA waiting = Evals performed correctly*D frac of evals need CA*(1+D frac evals need mult CA)
+ quick CA to prob needed + CA from regs
* corrective action/week
* New corrective actions coming to the managers for assignment to various groups that will perform the actions.

DR time to assign CA = 1
* weeks
* Time it takes a manager to assign corrective actions to procedure, modifications, or training changes.

****

D. Corrective action 2(view 52)

****

adj time to comp CA[xCorrective Action] = info eng unavail ratio
* time to comp CA[xCorrective Action]
* week
* The time delays in the completing corrective action adjusted for the availability of information engineers.

adj time to val CA[xCorrective Action] = time to val CA[xCorrective Action] * info mgr unavail ratio
* weeks
* The time delays in the validating the corrective action adjusted for the availability of information engineers.

CA change[PRO] = CA assignment * frac CA[PRO] + CA incorrect[PRO] * EFF MAIN OT INFO
CA change[MOD] = CA assignment * frac CA[MOD]
CA change[TRA] = CA assignment * frac CA[TRA] + CA incorrect[TRA] * EFF MAIN OT INFO

CA cmplted[xCorrective Action] = CA in Progress[xCorrective Action] /
adj time to comp CA[xCorrective Action]

CA in Progress[xCorrective Action] = SINTEG(CA change[xCorrective Action] -
CA cmplted[xCorrective Action],
INT CA in Progress[xCorrective Action],0,:NA:,:NA:,:NA:,:NA:)

CA incorrect[PRO] = CA validated[PRO] * ((1 - frac CA correct[PRO]) / frac CA correct[PRO])
CA incorrect[MOD] = 0
CA incorrect[TRA] = CA validated[TRA] * ((1 - frac CA correct[TRA]) / frac CA correct[TRA])

CA validated[PRO] = frac CA correct[PRO] * CA Waiting for Validation[PRO] /
adj time to val CA[PRO]
CA validated[MOD] = 0
CA validated[TRA] = frac CA correct[TRA] * CA Waiting for Validation[TRA] /
adj time to val CA[TRA]

CA Waiting for Validation[xcorrective Action] = SINTEG(CA cmplted[xCorrective Action] -
CA incorrect[xCorrective Action] - CA validated[xCorrective Action],
INT CA Waiting for Validation[xCorrective Action],0,:NA:,:NA:,:NA:,:NA:)

DR frac CA mod = 0.2
* dimensionless
* Fraction of corrective actions that are performed through modifications. Note that mods do not get performed in this flow, they are sent to scheduled work orders.

DR frac CA proc = 0.6
* dimensionless
* Fraction of corrective actions that will be procedure changes.

DR frac CA train = 0.2
* dimensionless
* Fraction of corrective actions that will be performed through training.

DR time to comp proc CA = 10
* weeks
* Time it takes to implement procedure changes within the utility.

DR time to comp train CA = 26
* weeks
* Time it takes a manager to validate that the training changes.

DR time to plan mod CA = 12
* weeks
* Time it takes to plan modifications for corrective actions.

DR time to val proc CA = 1
* weeks
* Time it takes a manager to validate that a procedure change was performed correctly.

DR time to val train CA = 2
* weeks
* Time it takes a manager to validate that the training changes.

frac CA[PRO] = DR frac CA proc
frac CA[MOD] = DR frac CA mod
frac CA[TRA] = DR frac CA train
* dimensionless
* Fraction of corrective action.

frac CA correct[PRO] = frac proc CA correct
frac CA correct[TRA] = frac train CA correct
frac CA correct[MOD] = 0

frac proc CA correct = 0.9 * EFF OT FATIGUE ENG
* dimensionless
* Fraction of corrective actions for training that are being performed correctly.

frac train CA correct =0.9 * EFF OT FATIGUE ENG
* dimensionless
* Fraction of corrective actions for training that are being performed correctly.

INT CA in Progress[xCorrective Action] = 200, 80, 200

INT CA Waiting for Validation[xCorrective Action] = 25, 0, 15

time to comp CA[PRO] = DR time to comp proc CA
time to comp CA[MOD] = DR time to plan mod CA
time to comp CA [TRA] = DR time to comp train CA
* weeks
* The time it takes to complete corrective action.

time to val CA[PRO] = DR time to val proc CA
time to val CA[TRA] = DR time to val train CA
time to val CA[MOD] = 0
* weeks
* Time it takes to validate corrective action.

****

D. Info Learning Curve(view 51)

****

frac Info CA competition = Info CA performed / Cumulative Info CA Performed

Info CA performed = CA validated[PRO] + CA validated[TRA]
* corrective action/week
* The information corrective actions that have been performed.

INT Cumulative Info CA Performed = 30 * 52 * 5
* corrective action
* The initial value of cumulative information corrective actions performed.

INT Defects Reduction = 0.95
* dimensionless
* The initial value of Defects Reduction.

Cumulative Info CA Performed = SINTEG(Info CA performed, INT Cumulative Info CA Performed,0,:NA:,:NA:,:NA:,:NA:)
* corrective action
* Cumulative corrective actions for information.

Def red rate decreasing = IF THEN ELSE(Time >5, - Defects Reduction * frac Info CA competition * mod info learning curve frac, 0)
* 1/weeks
* Amount of the Defects Reduction decreased from corrective actions.

Defects Reduction = SINTEG(Def red rate decreasing, INT Defects Rededuction,0,:NA:,:NA:,:NA:,:NA:)
* dimensionless
* Multiplier on all defects to reduce the number occurring. Serves to reduce defect causes from information use.

EFF DEF RED REPEAT REPS =F EFF DEFRED repeat reps(Defects Reduction)
* dimensionless
* Effect of defect reduction on repeat reports. As the Defects Reduction multiplier increases, more reports that the utility uses have been seen previously.

DR info learning curve fraction = 0.03
* dimensionless
* Information learning curve fraction. Fractional reduction in defect causes for a doubling of corrective actions.

mod info learning curve frac = -LN(1-(DR info learning curve fraction*training hours)) / LN(2)
* dimensionless
* Modified information learning curve fractions.

****

D. Evaluation(view 50)

****

INT Evaluations Waiting for Validation = 45
* evaluations
* The initial value of evaluations waiting for validation.

INT Evaluations in Progress = 275
* evaluations
* The initial value of evaluations in progress.

adj time to eval = DR time to eval * info eng unavail ratio
* weeks
* Time it takes to evaluation events for corrective actions, adjusted for availability of engineers.

adj time to val evals = DR time to val evals * info mgr unavail ratio
* weeks
* Time to validate evaluations, adjusted for the manager availability.

D eval eng unavail lim = 3
* dimensionless
* Maximum level that the engineer unavailability can be, before evaluations start becoming abandoned.

Evals validation initl = Items evaluated
* evaluations/week
* New items sent to managers to have their evaluations validated for completeness and correctness.

Evals abandoned = IF THEN ELSE((info eng unavail ratio > D eval eng unavail lim), (D frac evals abandoned * Evaluations in Progress), 0)
* evaluations/week
* Item evaluations abandoned because the unavailability of engineers becomes too high. This dynamically represents the lessening level of evaluation that occurs as engineers become busier.

Evals performed correctly = frac correctly eval * Evaluations Waiting for Validation / adj time to val evals
* evaluations/week
* Items that were validated to have been evaluated correctly by the engineering staff.

Evals performed incorrectly = Evals performed correctly * ((1- frac correctly eval) / frac correctly eval)
* evaluations/week
* Items that were evaluated incorrectly. Sent back for further evaluation.

Evaluations Waiting for Validation = SINTEG(Evals validation initl-Evals performed correctly
-Evals performed incorrectly,
INT Evaluations Waiting for Validation,0,:NA:,:NA:,:NA:,:NA:)
* evaluations
* Validations of evaluations performed by safety managers in progress.

Evaluations in Progress = SINTEG(+New item evaluations-Evals abandoned-Items evaluated,
INT Evaluations in Progress,0,:NA:,:NA:,:NA:,:NA:)
* evaluations
* Number of evaluations in progress by engineers.

frac correctly eval = 0.85 * EFF OT FATIGUE ENG
* dimensionless
* Fraction of evaluations that are performed to be correct.

D frac evals abandoned = 0.1
* dimensionless
* This is the fraction of evaluations that are abandoned because the time delay in evaluation are becoming too long.

Items evaluated = Evaluations in Progress / adj time to eval
* evaluations/week
* Completion of corrective action evaluation of items.

New item evaluations = (app reps+concerns from app SOER)+significant probs
+Evals performed incorrectly
* evaluations/week
* New items to be evaluated. These are potential problems, applicable reports and concerns / recommendations from applicable SOERs.

DR time to eval = 6
* weeks
* Time it takes to evaluation reports for corrective actions, independent of engineer usage.

DR time to val evals = 1
* weeks
* Time for a manager to validate evaluations.

****

D. Event 1(view 42)

****

start event pool reset 1 = IF THEN ELSE(Time <= 52, 52, QUANTUM(Time, 52))
* Periodic function for event pool reset.

start event pool reset 0 = IF THEN ELSE(Time <= 1, 1, 1 + QUANTUM(Time, 52))
* Periodic function for event pool reset.

Event pool reset = IF THEN ELSE(time plus > start event pool reset 0 :AND: time plus <
(start event pool reset 0 + TIME STEP), D event per year / TIME STEP, 0)
- IF THEN ELSE(time plus > start event pool reset 1 :AND: time plus <
(start event pool reset 1 + TIME STEP), Event Processing / TIME STEP, 0)
* events/week
*At the end and beginning of each year it zero's out the pool and then resets it the events per year value.

ident probs = Unusual event * D prob disc per unusual event + Site alert * D prob disc per alert
+ Site emergencies * D prob disc per emergency + D probs from major event
* problems
* Total number of identified problems from the three different type of event occurances.

INT Cum Alerts = 0
* alerts
* The initial value of cumulative alerts.

INT Cum Emergencies = 0
* emergencies
* The initial value of cumulative emergencies.

INT Cum Events = 0
* events
* The initial value of cumulative events

INT Cumulative Probs Reported = 0
* problems
* The initial value of cumulative problems reported.

INT Cum Unusual Events = 0
* events
* The initial value of cumulative unusual events.

INT Event Processing = 0
* events
* The initial value of event processing.

event occurance =EVENT OCCURANCES
* events
* Based on a random number this s the number of events occurring each week.

Cumulative Alerts = SINTEG(Site alert, INT Cum Alerts,0,:NA:,:NA:,:NA:,:NA:)
* alerts
* Total number of site alerts that have occurred.
*:SUPPLEMENTARY

Cumulative Emergencies = SINTEG(Site emergencies, INT Cum Emergencies,0,:NA:,:NA:,:NA:,:NA:)
* emergencies
* Total number of site emergencies that have occurred.
*:SUPPLEMENTARY

Cumulative Events = SINTEG(New event occurances, INT Cum Events,0,:NA:,:NA:,:NA:,:NA:)
* events
* Total number of events that occurred.
*:SUPPLEMENTARY

Cumulative Probs Reported = SINTEG(Increase in probs reported
, INT Cumulative Probs Reported,0,:NA:,:NA:,:NA:,:NA:)
* problems
* Total number of problems reported.
*:SUPPLEMENTARY

Cumulative Unusual Events = SINTEG(Unusual event, INT Cum Unusual Events, 0,
:NA:,:NA:,:NA:,:NA:)
* events
* Total number of events that occurred.
*:SUPPLEMENTARY

EFF ID PROB EPRI =F EFFidprobEPRI(ident prob ratio)
* dimensionless
* Effect of identified problems on EPRI. As the industry identified problem ratio increases, increasingly more research is initiated by EPRI to reduce problems.

EFF ID PROB WANO =F EFFidprobWANO(ident prob ratio)
* dimensionless
* Effect of identified problems on WANO. As more problems are identified in the US, more become identified by WANO as significant, so more reports will be produced. Notice that this is less than the inspection and EPRI effect because WANO is not that large of a contributor for problem information.

EFF SITE ALAND EMERG NRC INS =F EFFsitelandemerg NRCIns(SMOOTHI((Site alert
+10*Site emergencies), 12, 1))
* dimensionless
* Effect of identified problems on NRC inspections. As the ratio of industry problems increases, the NRC initiates more inspections in hope that they will be able to identify and correct more problems through regulations.

D event per year = 140
* events/year
* This is the maximum number of events that are alloweed to occur each year.

Event Processing = SINTEG(Event pool reset-Site alert-Site emergencies -Unusual event, INT Event
Processing,0,:NA:,:NA:,:NA:,:NA:)
* events
* Holds events that will eventually occur. Event occurances flow out when the probabilities dictate occurances. Limits the total number of event in to the event per year to the event per year level.

ident prob ratio = SMOOTHI(ident probs, 2,1) / SMOOTHI(ident probs,
D time horizon to comp ind probs, 10)
* dimensionless
* Ratio of a smooth of the last 2 weeks problems to a smooth of the problems occurring in the time horizon to compare problems in the industry. Used as input to effect report, research and investigation initiation based on the ratio of recent problems to past history.

Increase in probs reported = ident probs
* problems/week
* This is the number of problems reported each week.

New event occurances = event occurance
* events/week
* Events occurring per week.

D prob disc per alert = 10
* problems/alert
* Number of problems discovered from the site alert. Set at 10 ^ 1.

D prob disc per emergency = 100
* problems/emergency
* Problems discovered because of a site emergency. Set to 10 ^ 2.

D probs from major event = IF THEN ELSE((Time=156 :AND: event switch=1), 1000 , 0)

D prob disc per unusual event = 1
* problems/unusual event
* Number of problems discovered per for each unusual event occurance. Set to 10^0.

Site emergencies =se
* emergencies/week
* Site emergency occurances.

Site alert =sa
* alerts/week
* Site alerts occurances.

D time horizon to comp ind probs = 12
* weeks
* This is the number of weeks that people within the industry remember problems over when comparing the number of recent problems to those that have occurred in the past.

Unusual event =event occurance - Site alert - Site emergencies
* unusual event/week
* Unusual event occurances.

****

D. Event 2(view 43)

****

rand 1 = 100 * RANDOM 0 1()
rand 2 = 100 * RANDOM 0 1()
rand 3 = 100 * RANDOM 0 1()
rand 4 = 100 * RANDOM 0 1()
rand 5 = 100 * RANDOM 0 1()
rand 6 = 100 * RANDOM 0 1()

rand for num events = RANDOM 0 1()
* dimensionless
* Random number for events. Generates random number that is used in determining the number of events occurring per week.

sa = (test 1 + test 2 + test 3 + test 4 + test 5 +test 6)

* alerts
* Sums up the site alert occurrances from the probability processing of each event.

se =test 7 + test 8 + test 9 + test 10 + test 11 + test12

* emergencies
* Sums up the possibilities of site emergencies from the probability processing of each event.

test 1 = IF THEN ELSE((event occurance <1):OR:(rand 1<sa prob lim), 0, 1)
test 2 = IF THEN ELSE((event occurance <2):OR:(rand 2<sa prob lim), 0, 1)
test 3 = IF THEN ELSE((event occurance<3):AND:(rand 3<sa prob lim), 0, 1)
test 4 = IF THEN ELSE((event occurance<4):OR:(rand 4<sa prob lim), 0, 1)
test 5 = IF THEN ELSE((event occurance<5):OR:(rand 5<sa prob lim), 0, 1)
test 6 = IF THEN ELSE((event occurance<6):OR:(rand 6<sa prob lim), 0, 1)
test 7 = IF THEN ELSE((event occurance<1):OR:(rand 1<se prob lim):OR:(rand 1>50), 0, 1)
test 8 = IF THEN ELSE((event occurance<2):OR:(rand 2<se prob lim):OR:(rand 2>50), 0, 1)
test 9 = IF THEN ELSE((event occurance<3):OR:(rand 3<se prob lim):OR:(rand 3>50), 0, 1)
test10 = IF THEN ELSE((event occurance<4):OR:(rand 4<se prob lim):OR:(rand 4>50), 0, 1)
test11 = IF THEN ELSE((event occurance<5):OR:(rand 5<se prob lim):OR:(rand 5>50), 0, 1)
test12 = IF THEN ELSE((event occurance<6):OR:(rand 6<se prob lim):OR:(rand 6>50), 0, 1)

sa prob lim = 100 - DR base prob sa

* dimensionless
* Calculates the value that the random number must be greater than, and less then 100, for a site alert to occur.

se prob lim = 50 - DR base prob se

* dimensionless
* Calculates the value that the random number must be greater than, and less than 50, for a site emergency to occur.

DR base prob se = 0.25 * TIME STEP

* dimensionless
* Base probability of site emergency. Based on data from the NRC-1 emergency every 2-3 years. (1/340=0.25%)

DR base prob sa = 10 * TIME STEP

* dimensionless
* Base probability for site alert. Based on information from the NRC it is alert every 10 events. (1/10=10%)

EVENT OCCURANCES =F event occurances(rand for num events)

* events
* Number of events per week occurring. 1 to 6 events can occur per week based on the random number input to the lookup graph.

****

D. Information labor(view 55)

****

Chg info eng WTB = info eng work desired - Info Eng WTB

* engineers/week
* The change rate of info eng WTB.

info mgr work desired = SMOOTH(DR managers applied per job*(CA Waiting for Assignment
+Evaluations Waiting for Validation +CA Waiting for Validation[PRO]
+ CA Waiting for Validation[TRA]+Regulation Reviews Waiting for Assign
* DR mgr WTB per reg*DR info rev per mgr per week), 2)
* manager

info eng work desired = SMOOTH((CA in Progress[MOD] + CA in Progress[PRO]
+ Reports Waiting for Screening + Evaluations in Progress
+ SOERs Waiting for Screening + CA in Progress[TRA] + Prob Screening in Progress + (Regulations Under Technical Review + Reg Eval in Progress)
*DR info eng WTB per reg * DR info rev per eng per week), 2)
* engineers
* Information engineer work desired. Work desired to be completed by information engineers.

INT Info Eng WTB = 0
* work orders
* The initial value of information engineer work to be done.

INT Info Mgr WTB = 0
* manager
* The initial value of information manager work to be done

Chg info mgr WTB = info mgr work desired - Info Mgr WTB
* manager/week
* The change rate in info mgr WTB.

DR info eng WTB per reg = 25
* work orders/regulation
* information engineer work to be done per regulation.

info eng unavail ratio = IF THEN ELSE(Time <1:OR:Periodic Outage=1, 1, Info Eng WTB / (eng info rev comp + 1))
* dimensionless
* Information engineer unavailability ratio. Ratio of work to be done in the information sector to work available to be done by information engineers in the plant.

Info Eng WTB = SINTEG(Chg info eng WTB, INT Info Eng WTB,0,:NA:,:NA:,:NA:,:NA:)
* engineers
* The information engineer needed to work to be done.

info mgr unavail ratio = IF THEN ELSE(Time <0.5:OR:Periodic Outage = 1,1, Info Mgr WTB / mgr info rev comp + 1)
* dimensionless
* Information manager unavailability ratio.

Info Mgr WTB = SINTEG(Chg info mgr WTB, INT Info Mgr WTB,0,:NA:,:NA:,:NA:,:NA:)
* manager
* The information manager needed to work to be done.

DR managers applied per job = 0.2

DR mgr WTB per reg = 10
* manager/reg

****

D. INPO 1(view 45)

****

INT INPO Prob Analysis in Progress = 15
 * analysis
 * The initial value of INPO problem analysis in progress.

INT Prob Waiting for Screen by INPO = 10
 * problems
 * The initial value of problems waiting for screening by INPO.

adj INPO time to analyze probs = INPO eng unavail ratio * DR INPO time to analyze probs
 * weeks
 * INPO time to analyze problems adjusted by the engineer availability.

adj INPO time to screen event = DR INPO time to screen event * INPO eng unavail ratio
 * weeks
 * Base INPO screening time adjusted for the engineer availability.

DR frac sig probs = 0.8
 * dimensionless
 * Fraction of screened problems that are significant to the industry, as determined by INPO.

INPO prob analysis comp = INPO Prob Analysis in Progress / adj INPO time to analyze probs
 * analysis/week
 * Completion of INPO problem analysis. A fraction of these analyses yield recommendations to be sent out in SOER's.

INPO Prob Analysis in Progress = SINTEG(+INPO prob analysis init-INPO prob analysis comp,
 INT INPO Prob Analysis in Progress,0,:NA:,:NA:,:NA:,:NA:)
 * analysis
 * Number of problem analyses in progress. May become backlogged if INPO is overloaded with problems.

INPO prob analysis init = INPO significant probs
 * analysis/week
 * Initiation of further problem analysis. All significant problem are analyzed to see if corrective actions for corrective actions/recommendations

INPO probs screened = Probs Waiting for Screen by INPO / adj INPO time to screen event
 * problems/week
 * Problem screening by an INPO is completed. Problem is determined to be significant or non-significant.

INPO significant probs = INPO probs screened * DR frac sig probs
 * problems
 * Problems that are determined to be significant to the industry by INPO. These will lead to SEN,SER and SOER reports.

DR INPO time to analyze probs = 2
 * weeks
 * Base time it takes for an engineer to analyze a problem.

DR INPO time to screen event = 1
* weeks
* Time it takes an INPO engineer to screen a problem for its significance.

Probs reported to INPO = ident probs sent to INPO
* problems/week
* Problems discovered from site incidents that are reported that will initiate INPO reports.

Probs Waiting for Screen by INPO = SINTEG(+Probs reported to INPO-INPO probs screened.
INT Prob Waiting for Screen by INPO,0,:NA:,:NA:,:NA:,:NA:)
* problems
* Problems waiting for an INPO engineer to screen whether the events are significant to the industry or not. This may become backlogged if many problems are being analyzed in the INPO sector.

****

D. INPO 2(view 46)

****

Field invest planned 0 =(1- DR frac recs req quick SOER) * Recs Waiting for Further Investigation / adj INPO time to plan field invest

Field invest planned 1 = Field invest planned 0 * Coversion M

Coversion M = 0.5

Recs Waiting for Further Investigation = SINTEG(+New recs to inform -Field invest planned 0
-Quick SOER responses, INT Recs Waiting for Further investigation,
0,:NA:,:NA:,:NA:,:NA:)
* recs
* Recommendations waiting to be analyzed further, may immediately lead to SOER production or initiation of a field investigation.

INPO Field Invests in Progress = SINTEG(Field invest planned 1 - INPO rec field invest completed
, INT INPO Field Invests in Progress,0,:NA:,:NA:,:NA:,:NA:)
* investigations
* Number of field investigations on problems/recommendations in progress.

INT INPO Field Invests in Progress = 3
* investigations
* The initial value of INPO field investigation in progress.

INT Recs Waiting for Further investigation = 5
* recs
* The initial value of recommendations waiting for further investigation.

adj INPO time to plan field invest = DR INPO time to plan FI * INPO eng unavail ratio
* weeks
* Time it takes for INPO to plan a field investigation, adjusted by the availability of its engineers.

adj INPO time to produce quick SOER = DR INPO time to produce quick SOER * INPO eng unavail ratio
* weeks
* Time for INPO to quickly produce a SOER report adjusted for availability to engineers.

DR frac recs req quick SOER = 0.6

DR frac sig probs req recs = 0.5
* recs/problem
* Fraction of screened problems that are significant to the industry, as determined by INPO.

INPO rec field invest completed = INPO Field Invests in Progress / DR INPO time to comp FI
* investigations/week
* Number of investigations completed per week.

DR INPO time to comp FI = 6
* weeks
* Time it takes INPO to complete a field investigation. It is not adjusted for engineer availability because available engineers are on site. Leads to writing of SOER's.

DR INPO time to plan FI = 2
* weeks
* Base time it takes for INPO to plan a field investigation. Includes gathering of people, plans, equipment, etc.

DR INPO time to produce quick SOER = 1
* weeks
* This is the time it takes for INPO to produce a SOER report from its recommendations.

New recs to inform = INPO prob analysis comp * DR frac sig probs req recs
* recs/week
* New recs to appear in SOER reports.

Quick SOER responses = Recs Waiting for Further Investigation * DR frac recs req quick SOER /
adj INPO time to produce quick SOER
* SOER/week
* This flow creates SOER reports without any further investigation.

****

D. INPO 3(view 47)

****

INT SER Writing in Progress = 20
* SER
* The initial value of SER writing in progress.

adj time to produce SER = DR time to produce SER * INPO eng unavail ratio
* weeks
* Time it takes to produce a SER adjusted for the engineer availability.

DR eng needed per FI = 3
* engineers
* Number of engineers INPO needs to be on site for investigation of problems.

DR frac prob req SEN = 0.2
* dimensionless
* Fraction of problems that indicate informing the utilities quickly of the problem.

INPO eng available = IF THEN ELSE((INPO eng needed<DR max INPO eng available):AND:
(INPO eng needed>4), INPO eng needed, IF THEN ELSE((INPO eng needed<4), 4,
DR max INPO eng available))
* engineers
* Number of engineers that INPO is able to provide for problem processing, report writing, inspection, etc.

INPO eng needed = DR INPO eng needed per action * (Probs Waiting for Screen by INPO +
INPO Prob Analysis in Progress + Recs Waiting for Further Investigation +
SER Writing in Progress) + DR eng needed per FI * DR INPO eng needed per action
* INPO Field Invests in Progress
* engineers
* Total number of engineers needed to perform the pending actions.

DR INPO eng needed per action = 0.33
* engineers/action
* Fraction of engineer's time spent on performing an action. For example an engineer spends a quarter of his time in 2 weeks analyzing a new problem.

INPO eng unavail ratio = 1 + 0 * (IF THEN ELSE((INPO eng needed / INPO eng available) > 0.25,
INPO eng needed / INPO eng available, 0.25))
* engineers
* Ratio of engineers needed to engineers available in INPO. As this increases, the time delays in performing actions increases.

DR max INPO eng available = 20
* engineers
* Maximum number of engineers available at INPO to perform the actions within this sector.

SEN reports = INPO significant probs * DR frac prob req SEN
* reports
* SEN(Significant Event Notification). These are sent out as quickly possible to identify to the utilities that a significant event has occurred. May not contain too many details of the event, which will be expanded upon in the SER.

SER initiation = INPO significant probs
* SER
* All significant problems initiate the writing of a SER.

SER reports = SER Writing in Progress / adj time to produce SER
* SER/week
* SER reports from INPO that contain brief descriptions of a significant event or problem and why it was considered significant.

SER Writing in Progress = SINTEG(SER initiation-SER reports, INT SER Writing in Progress,
0,:NA:,:NA:,:NA:,:NA:)
* SER
* Number of SERs being written.

SOER reports = INPO rec field invest completed + Quick SOER responses
* reports
* SOER(Significant Operating Experience Reports). Reports contain INPO recommendations on actions to respond the significant events and problems is both quick SOER responses to recs and SOER responses from field investigations.

DR time to produce SER = 2
* weeks
* Time it takes to produce a SER.

****
D. Interacting with NRC 1(view 53)
****

INT Reg Reviews Waiting for Assign = 0
* regs
* The initial value of regulation waiting for assign.

INT Regulations Under Technical Review = 0.2
* regs
* The initial value of regulation under technical review.

adj time to assign reg review = DR time to assign reg review * info mgr unavail ratio
* weeks
* Time it takes to assign regulation reviews, adjusted for manager availability.

adj time to comp reg review = DR time to comp reg rev * info eng unavail ratio
* weeks
* Time it to complete regulation review, adjusted for engineer availability.

EFF REG ABAND TOT ENG and MGR =F EFF reg aband tot eng man(IF THEN ELSE(Regulations Under Technical Review > 0.15:AND:Time>104, DR frac regs des aband, 0))
* dimensionless
* Effect of regulation abandonment on total engineer and management.

EFF REG REV =F EFF regrev(DR frac of regs to review)
* dimensionless
* Effect of regulation review. As the reviewing of initiated regulations decreases, the effect will be to increase the time that it takes to evaluate and implement the regulations once they are put on the books at the NRC.

DR frac of regs to review = 0.9
* dimensionless
* Fraction of regulations initiated at the NRC that will be under review at the utility. As this decreases, it will take longer for the utility to review regulations once they are put on the books.

DR frac regs des aband = 0
* dimensionless
* Fraction of regulations that are determined to be incompatible when the probability arises that they are incompatible.

New regs to review = DR frac of regs to review * Initiating regulation
* regs/week
* New regulations that will undergo review at the utility. Reviewing regulations as they are being created allows for faster implementation of them, and for the chance that the utility may be able to remove the regulation.

Reg des aband = DR frac regs des aband * Regulations Under Technical Review / (DR time to comp reg rev/ 4)
* regs/week
* Regulations determined incompatible with the utilities goals.

Reg reviews assigned = Regulation Reviews Waiting for Assign / adj time to assign reg review
* regs/week
* Regulation reviews assigned to technical groups for review / comments.

Reg reviews completed = Regulations Under Technical Review / adj time to comp reg review
* regs/week
* Regulation reviews completed by the utility.

Regulation Reviews Waiting for Assign = SINTEG(New regs to review-Reg reviews assigned , INT Reg Reviews Waiting for Assign,0,:NA:,:NA:,:NA:,:NA:)
* regs
* Regulation reviews waiting to be assigned to technical groups for review.

Regulations Under Technical Review = SINTEG(+Tech review of new regs init -Reg des aband-Reg reviews completed, INT Regulations Under Technical Review,0,:NA:,:NA:,:NA:,:NA:)
* regs
* The regulations under technical review.

Tech review of new regs init = Reg reviews assigned
* recs/week
* Initiated of a technical review of regulations by the technical groups. The review includes both a review of the regulation, its impact, and the changes that will have to be made at the company.

DR time to assign reg review = 1
* weeks
* Time it takes for a manager/VP to assign a regulation review.

DR time to comp reg rev = 12
* weeks
* Time it takes to complete regulation review by the technical division.

****

D. Interacting with NRC 2(view 54)

****

INT NEI Abandon Effort in Progress = 0
* regs
* The initial value of NEI abandon effort in progress.

INT Reg Eval In Progress = 0
* regs
* The initial value of Regulation evaluation in progress.

adj time to comp reg eval = EFF REG REV * info eng unavail ratio * DR time to comp reg eval
- * weeks
- * Time to complete the regulation evaluations, adjusted for engineer availability and for the fact that regulations are being reviewed while under development at the NRC.

CA from regs = DR CA per reg * New reg evals completed
- * corrective actions
- * Corrective actions that come from regulations.

DR CA per reg = 253
- * corrective action/regulation
- * Corrective action per regulation.

DR frac regs abandoned = 1
- * dimensionless
- * This is the fraction of regulation abandon effort that is effective in getting a regulation abandoned by the NRC.

NEI Abandon Effort in Progress = SINTEG(NEI effort to aband reg - Regs abandoned effort comp,
INT NEI Abandon Effort in Progress,0,:NA:,:NA:,:NA:,:NA:)
- * regs
- * This is the effort that NEI is putting in to get a regulation abandoned by the NRC.

NEI effort to aband reg = Reg des aband
- * regs/week
- * If the utility dislikes regulations, they will have NEI work with other utilities to spend the effort to abandon the regulation before it hits the book.

New reg evals completed = Reg Eval in Progress / adj time to comp reg eval
- * regs/week
- * Completion of regulation evaluation leads to corrective actions within the utility.

New regs to implement = Enacting regulation
- * regs/week
- * This is newly booked regulations by the NRC that need to be implemented within the utility.

Reg Eval in Progress = SINTEG(+New regs to implement-New reg evals completed
, INT Reg Eval In Progress,0,:NA:,:NA:,:NA:,:NA:)
- * regs
- * This is the further evaluation of regulation within the utility before they are implemented.

regs abandoned from NEI effort = DR frac regs abandoned * Regs abandoned effort comp
- * regs/week
- * This is the number of regulations that are being abandoned by the NRC.

Regs abandoned effort comp = NEI Abandon Effort in Progress / DR time to influence NRC
- * regs/week
- * This is the completion of abandoning effort by NEI. At this point a portion of the regulations will be abandoned before they become on the books.

DR time to comp reg eval = 6
- * weeks
- * Base time complete regulation evaluations.

DR time to influence NRC = 12
* weeks
* This is the time it takes for NEI to influence the NRC into abandoning a regulation.

****

D. Problem reporting(view 44)

****

Completion[xprob reporting] = Report in Progress[xprob reporting]
/ D time to completion[xprob reporting]

D frac probs need in = 0.5
* dimensionless
* Fraction of incoming problems to the NRC that initiate the writing of IN's. This fraction may reduces the number of problem reports that produce IN's because the problem may be only plant specific, problem may have already initiated an IN, or may not be worthwhile for the industry to know.

D time to completion [xprob reporting] = 26, 4, 12, 4

DR base EPRI res = 1
* progs/week
* Base rate that EPRI initiates research projects.

DR base VEN res = 1
* progs/week
* Base vendor research rate.

DR base WANO rep = 2
* reports/week
* Base rate that WANO produces reports of international significance.

DR frac probs sent to INPO = 1
* dimensionless
* Fraction of total problems identified that are sent to INPO for analysis.

ident probs sent to NRC = DR frac probs sent to NRC * ident probs
* problems
* Number of problems sent to NRC to be reviewed for Information Notifications (IN).

Initiation[VEN] = DR base VEN res + ident probs sent to vendors
Initiation[NRC] = D frac probs need in * ident probs sent to NRC
Initiation[EPR] = DR base EPRI res * EFF ID PROB EPRI
Initiation[WAN] = DR base WANO rep * EFF ID PROB WANO

INT Report in Progress[xprob reporting] = 0, 0, 0, 0
* reporings
* The initial value of report in progress.

DR frac probs sent to NRC = 1
* dimensionless
* Fraction of total identified problems sent to NRC for analysis.

DR frac probs sent to vendors = 0.1
* dimensionless
* Fraction of total identified problems that are sent to vendors to initiate research.

ident probs sent to INPO = DR frac probs sent to INPO * ident probs
* problems
* Number of problems given to INPO for analysis. Will eventually produce Significant Event Notification(SEN), Significant Event Reports(SER), and Significant Operating Experience Reports(SOER).

ident probs sent to vendors =DR frac probs sent to vendors * ident probs
* problems
* Number of problems sent to vendors that will initiate research on problems with their products.

Report in Progress[xprob reporting] = SINTEG(+Initiation[xprob reporting]-Completion[xprob reporting], INT Report in Progress[xprob reporting], 0,:NA:,:NA:,:NA:,:NA:)
* reporings

****

D. Problem screening(view 49)

****

probs not screened by NWE=Probs Waiting for Screening * (1 - DR frac probs screen by NWE)
* problems/week
* Problems not screened by the NWE, Occurs because of a lack of time or availability.

INT Prob Screening in Progress = 30
* problems
* The initial value of Problem screening in progress.

INT Prob Waiting for Screening = 0
* problems
* The initial value of Problem waiting for screening.

adj time to screen prob = DR time to screen probs * info eng unavail ratio
* weeks
* Time to screen problems, adjusted by the engineer availability.

eff inc probs NWE = ZIDZ(SMOOTHI(New incoming probs, 4, 20), New incoming probs)
* dimensionless
* This effect changes the fraction of problems screened by the NWE based on the ratio of incoming problems to the number of incoming problems smoothed over time.

D frac of probs req eval = 0.75
* evaluations / problem
* Fraction of screened problems that will require further analysis.

DR frac prob need quick CA = 0.25
* actions/problem
* Fraction of problems screened by the NWE that dictate that quick corrective actions be taken.

DR frac probs screen by NWE = 0.25 * eff inc probs NWE
* dimensionless
* Fraction of problems that the NWE is able to screen, this number is adjusted if the number of incoming problems is greater than it has been in the past.

New incoming probs = IF THEN ELSE((Dfcts discvrd lost>0), Dfcts discvrd lost
* DR probs per defect, 0)
* problems/week
* Problems or potential problems discovered through defects or a combination of defects.

New prob screen = probs not screened by NWE + Prob screened by NWE - quick CA to prob needed
* problems/week
* Problems screened by the NWE and not screened by the NWE will be screened by other groups for determination of whether the problem is significant.

Prob screened by NWE = Probs Waiting for Screening * DR frac probs screen by NWE /
time for NWE to screen
* problems/week
* Problems screened by the NWE. Screened for applicability and for need for quick CA's.

Prob Screening in Progress = SINTEG(New prob screen-Prob screening completion
, INT Prob Screening in Progress,0,:NA:,:NA:,:NA:,:NA:)
* problems
* Screening of problems or potential problems in progress.

Prob screening completion = Prob Screening in Progress / adj time to screen prob
* problems/week
* Completion of problem screening by the technical programs groups. Determined whether problem is significant to the utility or not.

DR probs per defect = 1 / 50
* problems/defect
* Number of problems or potential problems discovered per defect. Many defects go on noticed because that are so minor, or numerous defects combine to produce a problem or potential problem.

Probs Waiting for Screening = SINTEG(New incoming probs-Prob screened by NWE
-probs not screened by NWE, INT Prob Waiting for Screening,
0,:NA:,:NA:,:NA:,:NA:)
* problems
* All problems discovered are first sent to the Nuclear Watch Engineer for screening of the need for quick corrective actions.

quick CA to prob needed = Prob screened by NWE * DR frac prob need quick CA
* actions/week
* If the NWE sees a problem that dictates that corrective actions (determined by the NWE) be taken quickly, he will pass them on directly to the manager who disseminates corrective actions to the groups.

significant probs = Prob screening completion * D frac of probs req eval
* evaluations/week
* Problems determined significant to the utility, and need further analysis, and possible corrective actions.

time for NWE to screen = TIME STEP
* weeks
* Time it takes to screen problems under normal workload conditions.

DR time to screen probs = 2
* weeks
* Time it takes to screen problems under normal workload conditions.

****
D. Public reporting(view 57)
****

time plus = Time + (TIME STEP / 2)

start report score = IF THEN ELSE(Time<=1, 1, 1 +
QUANTUM(Time, 52/ DR SALP reporting per year))
* weeks
* Periodic function for report score.

INT Reported SALP Score = 0
* dimensionless
* The initial value of reported SALP score.

dfct operating reports = press release from dfcts * FRAC of PRESS RELEASE PRINT as OP REPS
* reports
* Number of press releases that are issued because of defects.

DR dfcts per press release = 1000
*. defects/pr
* Number of defects that occur before a press release is made. Also can be though of as a number of defects that contribute to a problem or potential problem that.

EFF SALP LPO =F EFFSALPlocpub opp(Reported SALP Score)
* dimensionless
* Effect of SALP score on local public opposition.

EFF SALP NPO =F EFFSALPnat pub opp(SMOOTHI(Reported SALP Score, 52, 2))
* dimensionless
* Effect of SALP score on national public opposition. National SALP average will be taken as a smooth over the year of the SALP scores.

FRAC of PRESS RELEASE PRINT as OP REPS =F frac of press releases print as op reps (press release ratio)
* printed reps/pr/week
* Fraction of press releases that get printed in the papers. If more defects are occurring recently, than in the past, more printings will occur.

press release from dfcts = total new dfcts / DR dfcts per press release
* pr/week
* Number of press releases that are issued because of defects.

press release ratio = SMOOTHI(press release from dfcts, 4, 1) /
SMOOTHI(press release from dfcts, 26, 1)

* dimensionless
* Ratio of a smooth of the last 4 week's releases to a smooth of the last 26 week's releases.

Report score = IF THEN ELSE(time plus > start report score :AND:time plus < (start report score + TIME STEP), (SALP - Reported SALP Score) / TIME STEP, 0)

* This flow acts to change the reported SALP score. Resets the previous value to the new current SALP rating.

Reported SALP Score = SINTEG(Report score, INT Reported SALP Score,0,:NA:,:NA:,:NA:,:NA:)

* dimensionless
* This is the SALP score as reported. Changes the number of times set in SALP reporting per year.

DR SALP reporting per year = 4

* dimensionless
* Number of times that SALP scores are reported to the public each year.

****

D. Info SALP Effect(view 58)

****

Cumulative Reports Available = SINTEG(New reports, INT Cumulative Reports Available,0,:NA:,:NA:,:NA:,:NA:)

* reports
* Cumulative number of available reports for the utility to learn from.

INT Cumulative Reports Available = 1

* reports
* The initial value of cumulative reports available.

INT Total Report Analysis Abandoned = 0

* reports
* The initial value of total report analysis abandoned.

New reports = Incoming reports + Incoming SOERs + New incoming probs

* reports/week
* Increase in the number of new reports that have come into the utility.

Rep analysis abandoned = CA abandon + Evals abandoned + Reports abandoned

* reports/week
* Reports abandoned because of unavailability of managers and engineers. Comes from abandonment during evaluation or when corrective actions are assigned.

report analysis ratio = (Cumulative Reports Available - Total Report Analysis Abandoned) /
Cumulative Reports Available

* dimensionless
* Ratio of the number of reports analyzes to the number of reports available.

Rep analysis reopened = EFF SALP INFO * Total Report Analysis Abandoned

* reports/week
* Reports analyses reopened because of pressure to improve performance and safety.

Total Report Analysis Abandoned = SINTEG(Rep analysis abandoned-Rep analysis reopened, INT Total Report Analysis Abandoned,0,:NA:,:NA:,:NA:,:NA:)

* reports
* Total number of report analyses abandoned.

****

D. Report screening(view 48)

****

Incoming reports = Completion[EPR] + Completion[NRC] + SEN reports + SER reports + Completion[VEN] + Completion[WAN] + Rep analysis reopened

* reports/week
* Includes all other incoming reports that contain useful information. Will be screened for applicability.

INT Reps Waiting for Screening = 70

* reports
* The initial value of reports waiting for screening.

INT SOERs Waiting for Screening = 5

* SOER
* The initial value of SOERs Waiting for Screening.

adj time to screen reps = DR time to screen reps * info eng unavail ratio

* weeks
* Time to screen reports adjusted for availability of engineers.

app reps = Reports screened * frac reps dtmd app

* reports/week
* Applicable report. Number of screened reports that are determined applicable.

app reps prev anal = Reports screened * DR frac reps prev analyzed

* reports/week
* Number of screened reports that had been previously analyzed.
*:SUPPLEMENTARY

app SOER = SOER screened * DR frac SOER dtmd app

* SOER/week
* SOERs determined applicable to our utility.

concerns from app SOER = app SOER * DR concerns per SOER

* concerns/week
* New concerns from SOERs to be analyzed further.

DR concerns per SOER = 5

* concerns/SOER
* Average number of utility concerns that come from SOERs.

DR frac report abandoned = 0.4

* dimensionless
* Fraction of reports that are abandoned before they are screened, if information engineers are not available.

frac reps dtmd app = 1 - DR frac reps prev analyzed
* dimensionless
* Fraction of screened reports that are applicable an need further analysis.

DR frac reps prev analyzed = 0.3 * EFF DEF RED REPEAT REPS
* dimensionless
* Number of screened reports that have problems that had previously been screened by the utility.

DR frac SOER dtmd app = 0.8
* dimensionless
* Fraction of screened SOERs that are applicable to the utility.

Incoming SOERs = SOER reports
* SOER/week
* SOERs coming into to the utility for analysis.

non app reps = Reports screened * (1 - frac reps dtmd app - DR frac reps prev analyzed)
* reports/week
* Number of screened reports that are determined non-applicable.
*:SUPPLEMENTARY

no app SOER = SOER screened * (1 - DR frac SOER dtmd app)
* SOER/week
* SOERs determined to be non-applicable to our utility.
*:SUPPLEMENTARY

Reports abandoned = IF THEN ELSE((info eng unavail ratio>4), DR frac report abandoned * Reports Waiting for Screening, 0)
* reports/week
* Reports abandoned before they are screened because of engineer workload.

Reports screened = Reports Waiting for Screening / adj time to screen reps
* reports/week
* Reports undergoing screening to determine applicability to the utility.

Reports Waiting for Screening = SINTEG(Incoming reports-Reports abandoned -Reports screened, INT Reps Waiting for Screening,0,:NA:,:NA:,:NA:,:NA:)
* reports
* Reports waiting to be screened for applicability. May become backlogged if the operating experience program receives too much information as the same time.

SOER screened =SOERs Waiting for Screening / DR time to screen SOER
* SOER/week
* SOER screening completion.

SOERs Waiting for Screening = SINTEG(Incoming SOERs-SOER screened , INT SOERs Waiting for Screening,0,:NA:,:NA:,:NA:,:NA:)
* SOER
* SOER waiting to be screened by an engineer. Screening determined whether the SOER is applicable or non-applicable.

DR time to screen reps = 3
* weeks
* Time for engineers to screen reports for applicability.

DR time to screen SOER = 1

* weeks
* Time to screen SOER. Not adjusted by the engineer availability because these are always screened as soon as possible.

E. Financial Resources Sector (view 59 - 74)

****

E. Bond rating(view 71)

****

IND of CREDIT PFS =F Ind of Credit PFS(DE ratio + (Perceived Safety by Finance Market / 50)
+ PUC aggreability + SMOOTH((Chg total equity - DF) / TIME STEP, 26)
+ D system reliability / 4)

* dimensionless
* Indicator of Credit Agency's Perceived Financial Soundness.

INT Credit Agencys Perceived Fin Soundness = 70

* dimensionless
* This is the initial value of credit agenys perceived financial soundness.

DF = DELAY FIXED(Chg total equity, TIME STEP, 0)

Bond DT = ((IND of CREDIT PFS - Credit Agencys Perceived Fin Soundness)
/ time to change BR)

* {/week}
* This is the change in perceived financial soundness per week.

BOND RATING =F Bond Rating(FORECAST(Credit Agencys Perceived Fin Soundness, 208, 104))

* dimensionless
* This will be on a scale of 1-12 representing a rating from CCC, B-, B+, BB-, BB+, BBB-, BBB+, A-,A+, AA-, AA+, AAA.

Credit Agencys Perceived Fin Soundness = SINTEG(Bond DT, INT Credit Agencys Perceived Fin
Soundness,0,:NA:,:NA:,:NA:,:NA:)

* dimensionless
* This is the perceived risk of the utility defaulting on its debt on a 0-100 scale. 0 is default - 100 is no risk-equivalent to a AAA rating.

DE ratio = Debt / Total Equity

* dimensionless
* Debt to Equity Ratio. This is the most common measure of financial soundness, used to determine how much relative debt a utility has.

EFF BR PUC =F EffBRPUC(BOND RATING)

* dimensionless
* This is the effect of a good bond rating on the PUC's deciding the utility management is being prudent. Also, if the bond rating is bad enough it has the effect of artificially improving the ROE so that the utility can meet its debt obligations.

EFF BR STOCK =F EFFBRStock(BOND RATING)

* dimensionless
* This is the effect on Beta Debt that the bond rating generates.

time to change BR = 26 * ((IND of CREDIT PFS+Credit Agencys Perceived Fin Soundness)
/ Credit Agencys Perceived Fin Soundness)

* weeks
* This is the time it takes the Bond Rates to change the rating of a utility. It can change rapidly if the utility's finances deteriorate but normally takes 6 months.

****

E. Budgeting parameter 1(view 67)

****

init BT = INITIAL(budgeted taxes)
init DP = INITIAL(debt payments)
init OPS = INITIAL(ops)
init WFC = INITIAL(week fix cost)

max bud parts = discretionary budget * DR frac bud parts
* million dollars/week
* This is the maximum allowed to be spent on managers.

max bud eng = discretionary budget * DR frac bud eng
* million dollars/week
* This is the maximum amount of money to be spent on engineers.

max bud mgr = discretionary budget * DR frac bud mgr
* million dollars/week
* This is the maximum amount of money allowed to be spent on managers.

max budget maint = (discretionary budget * DR frac bud mech) - insp budget - training budget
* million dollars/week
* This is the weekly desired amount of money allocated initially to mechanics except inspection process and their training.

init BPC = INITIAL(bought pow cost)

insp budget = discretionary budget * DR frac bud mech * frac lab bud alloc disc insp
* million dollars/week
* Inspection budget.

bud maint parts = DR frac part bud maint parts * max bud parts
* million dollars
* Maint parts as opposed to new parts.

budgeted taxes = desired weekly profit * 0.36 + 0.0006 * Book Value Assets
* million dollars/week
* This is estimated taxes based on test year revenues.

cb switch = 0
* dimensionless
* This turns on across the board utility cutbacks.
*:SUPPLEMENTARY

desired profit margin = desired weekly profit / discretionary budget
* percentage
* Desired profit margin. This is the amount of profit percentage the utility desires.

discretionary budget = (week budget - required costs - desired weekly profit)
* million dollars/week
* This is the amount of money the manager can play with each week.

di ch from base = 0

frac lab bud alloc disc insp = 0.1 - STEP(di ch from base,160) + STEP(di ch from base, 390)
* dimensionless
* Fraction of the labor budget which are spent on discretionary inspections.

DR frac bud eng = 0.175
* dimensionless
* This is the desired portion of the discretionary budget for engineering.

DR frac bud lobby = 0.01
* dimensionless
* This is the portion of the discretionary budget for lobbying.

DR frac bud mech = 0.525
* dimensionless
* Fraction of budget allocated for mechanical labor.

DR frac bud mgr = 0.1
* dimensionless
* This is the portion of the discretionary budget for manager.

DR frac bud parts = 0.1
* dimensionless
* This is the portion of the discretionary budget allocated for parts.

DR frac bud training = 0.1

DR frac part bud maint parts = 0.8
* dimensionless
* This is the weekly fraction of the part budget to be spent on only maintenance parts as opposed to capital parts.

max bud lobby = discretionary budget * DR frac bud lobby
* dimensionless
* Maximum budget for lobbying.

max eng =max bud eng / (DR eng annual salary / 52)
* engineers
* This is the maximum number of engineers allowed to be hired.

max mech budget = insp budget + max budget maint + training budget
* million dollars/week
* The maximum weekly budget for mechanics.

max mgr = max bud mgr / (DR mgr annual salary / 52)

DR mgr annual salary = 100000 / 1e+006
* million dollars
* Manager annual salary.

required costs = - init DP + init OPS + init WFC + init BT + init BPC
* million dollars/week
* These are costs which the utility has little control over in the model.

training budget = discretionary budget * DR frac bud training * DR frac bud mech
* (1 -STEP(D layoff fraction* 3, 200))
* million dollars/week
* Training budget.

week budget = (test yr rev / (52 * 1e+006)) * (1 - eviliness)
* million dollars/week
* This is the amount of money predicted for the utility based on test year revenues.

****

E. Budgeting parameter 2(view 68)

****

bud div = desired weekly profit * DR frac div
* million dollars/week
* This is the estimated weekly outlay for shareholders.

budget max = DR frac bud eng + DR frac bud lobby + DR frac bud mech
+ DR frac bud parts + DR frac bud mgr
* dimensionless
* This is the total allowed discretionary budget.
*:SUPPLEMENTARY

desired weekly profit = Total Equity * D desired return on equity / 52
* million dollars/week
* This is the utility's goal of return in investment per week.

D desired return on equity = 0.06
* percentage
* This is the utility's goal for return on Equity.

DR frac div = 0.75
* dimensionless
* This is the fraction of profits which go to dividends instead of retained earnings.

max Mstaff =max mech budget / (D overhead eff * DR standard hours * DR hrly cost labor
* DR mech experience cost factor)
* workers
* This is the maximum number of maintenance staff based on budget.

profit message = 1 - (desired profit margin + DR frac bud eng +DR frac bud lobby + DR frac bud mech
+ DR frac bud mgr + DR frac bud parts)
*:SUPPLEMENTARY

****

E. Debt(view 74)

****

INT Debt = 682.5
* million dollars
* The initial value of Debt.

Debt =SINTEG(Debt increased-Debt retired, INT Debt,0,:NA:,:NA:,:NA:,:NA:)
* million dollars
* Debt.

D debt factor = 0.6
* dimensionless

Debt increased = IF THEN ELSE((DE ratio<=10), desired liab, 0)
* million dollars/week
* This is the amount of dollars per week incorporated.

Debt retired = ABS(debt payments)
* million dollars/week
* Debt Retired. This is the dollars spent of debt payments.

desired liab = IF THEN ELSE((net cash flow<0), ((ABS(net cash flow) + Taxes) * (D debt factor+ (D equity factor*(1-EFF MBRDNE)))), 0)

stock equity = Book Value Assets-Debt
*:SUPPLEMENTARY

****
E. Economics random effects(view 72)
****

pi = 3.14

economic cycles =0.2 * SIN(2 * pi * Time / 520) + 1
* dimensionless
* Economy Cycle Represents the cyclic effect the economy has on the stock and bond prices during expansions and recessions. 1 indicates no effect and greater than 1 indicates expansion which will tend to inflate the price and ratings.

inflation rate = IF THEN ELSE((Time > 156), 0.04, 0)
* dimensionless
* Inflation rate.

market effects = economic cycles * (random effects^1.3) * D speculation factor ^ (U internal rate of return * Time)
* dimensionless
* Total of all other effects.

random effects = ABS(RANDOM NORMAL() * 0.03 +1)
* dimensionless
* This is the random jitters which occur in the stock market daily.

D speculation factor = 1
* dimensionless
* Use this factor as an additional factor to represent speculations on the financial future of the utility. Depending on the volatility. of the market, this factor can give further unreliability of prediction. It will be set to 1 at the start of this model.

time increase in value = ((inflation rate * Time + U internal rate of return * Time) / 2)+1

* percent/year
* This is the increase in value of stock, debt and invested assets.
*:SUPPLEMENTARY

U internal rate of return = 0.04 + ((10 - BOND RATING) / 200)

* percentage
* This is the rate the utility must pay investors on average for its bonds.

****

E. Financial safety(view 73)

****

INT Perceived Safety by Finance Market = CUR IND of PER SAF

EFF PS FM =F EFFPSFM(Chg perceived safety)

* dimensionless
* This factor represents the impact a change in perceived safety has on the financial markets. It creates the saw tooth reference mode of the impact on financial markets being drastically negative when safety drops but lukewarm positive when safety improves.
*:SUPPLEMENTARY

Chg perceived safety =(CUR IND of PER SAF - Perceived Safety by Finance Market) / delay in adj saf perc

CUR IND of PER SAF =F CurIndPerSaf(EFF FO PS * EFF LPO PER SAF * EFF OPS PS * EFF NPO FER SAF * EFF SR PS* EVENT EFFECT)

* dimensionless
* Perceived safety represents the public, financial and PUC's relative perception of how safe a utility is. The model assumes that although the absolute value of the effects of the safety indicators are different, their rough relative value is the same. Thus if the Puc thinks that a utility is unsafe so do the financial markets. This 'perceived safety' measures the safety of the plant as well as threats of the industry because if other plants are unsafe, public perception of even safe plants is obviously affected.

delay in adj saf perc =F Delay in adj Saf perc(CUR IND of PER SAF - Perceived Safety by Finance Market)

* dimensionless

EFF OPS PS =F EFFOpsPS(capacity online + (Periodic Outage * 100))

* dimensionless
* Effect of OPS on perceived safety. This is the effect of capacity rating on perception of reactor safety by financial community.

EFF FO PS =F EFFFOPS(EFF Forced Outage)

* dimensionless
* Effect of forced outages on perceived safety. This is the effect recent forced outages have on perceived safety by the financial community.

EFF PS PUC = IF THEN ELSE(evil puc fun, EFF PS PUC E, EFF PS PUC G)

EFF PS PUC E =F EFFPSPUC E(Perceived Safety by Finance Market)
* dimensionless
* This is the effect the financial perceived safety of the reactor has on the PUC's prudence. As safety drops, the prudence drops. However, at a certain point, the safety drops so low that punishing the utility monetarily will probable cause them to go bankrupt with no hope of ever getting better safety. So, assuming a benevolent PUC, when safety becomes low enough it starts giving the utility rate increases under the auspices of improving utility.

EFF PS PUC G =F EFFPSPUC G(Perceived Safety by Finance Market)
* dimensionless
* This is the effect the financial perceived safety of the reactor has on the PUC's prudence. As safety drops, the prudence drops. However, at a certain point, the safety drops so low that punishing the utility monetarily will probable cause them to go bankrupt with no hope of ever getting better safety. So, assuming a benevolent PUC, when safety becomes low enough it starts giving the utility rate increases under the auspices of improving the utility.

EFF PS StRISK =F EFFPSStRisk(Perceived Safety by Finance Market)
* dimensionless
* This is the effect that the risk of core has on stock price.

EFF SR PS =F EFFSRPS(SALP)
* dimensionless
* Effect of safety rating on perceived safety. This is the combination of SALP scores to influence perceived safety.

EVENT EFFECT =F Event Effect(event switch * (STEP(1,156) - SMOOTH3(STEP(0.95, 166), 62)))
* dimensionless
* Event effect. This takes into account the time over which the event's effects impact the public significantly.

Perceived Safety by Finance Market =SINTEG(Chg perceived safety, INT Perceived Safety by Finance Market,0,:NA:,:NA:,:NA:,:NA:)
* dimensionless
* Perceived Safety By Financial Markets. This is a measure of how the financial markets measure the risk of losing the reactor due to an accident. It is different than what the public, engineers, or NRC use to determine the risk of a core melt.

utility ave SALP = SMOOTH3I(SALP, 208, 3) * EVENT EFFECT
* dimensionless
* This is the average nationwide SALP rating financial people use to compare our utility in terms of performance.
*:SUPPLEMENTARY

****
E. Internal finance 1(view 59)
****

INT Book Value Assets = INT Book Investment
* million dollars
* The initial value of book value assets.

DR decom costs = 200

INT Book Investment = 2000

INT Accum Dep XA = 0
* million dollars
* The initial value of accumulative depreciation XA.

Book Investment = INTEG(0, INT Book Investment)

INT Liquid Assets = 5
* million dollars
* The initial value of liquid assets

INT Retained Earnings = 1
* million dollars
* The initial value of retained earnings.

Accum Dep XA = SINTEG(Dep XA, INT Accum Dep XA,0,:NA:,:NA:,:NA:,:NA:)
* million dollars
* Accumulated depreciation XA. This is the accumulated contra-asset of straight line depreciation of the utility's capital equipment and property.
*:SUPPLEMENTARY

Book Value Assets = SINTEG(+Investment-Dep XA, INT Book Value Assets,0,:NA:,:NA:,:NA:,:NA:)
* million dollars
* Net present value of business in millions of dollars.

bought revs = (bought power / 100) * rate per kwh * 168 * 1000 * (DR power rating / 1e+006)
* million dollars/week
* This is the cash raised through wheeling to make up for power not generated by the plant.

cap costs = - debt payments
* million dollars/week
* These are costs which are spent on repaying debt, mostly from building the nuclear plants.

Cash prov by financing activities = Debt increased + equity raised
* million dollars/week
* Cash provided by financing activities.

Ch RE = net income - Dividends
* million dollars/week
* This is the left over profits which increases the value of the utility.

Costs = O and M costs + cap costs
* million dollars/week
* Total spending by the utility.

Dep XA = depreciation
* million dollars/week
* Straight line reduction in worth of property plant and equipment.

depreciation = 0.025 * (Book Investment / 52 + DR decom costs) / 52
* million dollars/week
* Straight line depreciation of assets including decomm costs. Depreciated 40 years.

DR dividend factor = 0.75
* dimensionless
* This is the percent of after tax profits which go to the shareholders.

Dividends = net income * DR dividend factor
* million dollars/week
* Dividend paid to stockholder.

frac ch RE = ZIDZ(Ch RE, Retained Earnings)*52
* dimensionless
*:SUPPLEMENTARY

gross margin = Revenues - Costs
* million dollars/week
* This is the just revenues minus costs.

Investment = IF THEN ELSE(Liquid Assets<=0, 0, bought eq cap inv$+Cptl imp cash)
* million dollars/week
* The millions of dollars investment into plant and equipment.

Liquid Assets = INTEG(Cash prov by financing activities+Revenues - Ch RE - Costs - Dividends -Investment-Taxes, INT Liquid Assets)
* million dollars
* This is the amount of short term cash the utility has. If it goes negative this represents short term borrowing the utility undertakes. Eventually this is made up for by long term borrowing. Unfortunately interest charges for short term borrowing are not calculated yet.

net cash flow = gross margin - Investment
* million dollars/week
* This is the cash after investment is taken out.

net income = gross margin - Taxes -Dep XA
* million dollars/week
* This is the net profits after taxes of the utility.

prod revs = (capacity online / 100) * (rate per kwh * 1000 *168) * DR power rating / 1e+006
* million dollars
* This is the dollars raised through power produced at the plant.

Retained Earnings = INTEG(Ch RE, INT Retained Earnings)
* million dollars
* These are million dollars' left over and retained by the utility. Their use is not specified.

Revenues = bought revs + prod revs
* million dollars/week
* This is the cash flow to the utility per week. Constants: 100-converts % cap util to fraction, 1000 converts per kwh to per Mkwh. 168 converts hours to weeks, and 1E6 converts $'s to millions of dollars.

Taxes = 0.35 * (gross margin - depreciation) + 0.0006 * Book Value Assets
* million dollars/week
* Taxes.

****

E. Internal finance 2(view 60)

****

INT New Part Cap Inv $ = Book Investment * 0.01
* million dollars
* The initial value of new part capital investment.

INT NPV Income = 0
* million dollars
* The initial value of NPV income.

Cptl imp cash = FRAC MAX ALLOC * desired $ to NP cap
* million dollars/week
* This is the money invested in capital equipment such a new steam generators.

assets = Book Value Assets+Liquid Assets
* million dollars

cap inv mult = 1

desired $ to NP cap = IF THEN ELSE((Liquid Assets>0), max bud parts * cap inv mult * 0.1, 0)

discount factor = 1 / ((1 + (DR discount rate / (52 * 100)))^(Time))
* dimensionless

DR discount rate = 4
* percentage
* Cost of money.

fin error = assets - (liabilities + shareholder's equity)
*:SUPPLEMENTARY

FRAC MAX ALLOC =F Frac max alloc(Liquid Assets)
* dimensionless
* This determines what percentage of maximum investment into capital based on the amount of liquid assets. If there are no liquid assets, no investment is made.

Chg income = net income / ((1 + (0.03 / 52))^Time)
* million dollars/week
* This sums the net income divided by the interest rate. To obtain the NPV of income.

liabilities = Debt

New Part Cap Inv $ = SINTEG(Cptl imp cash-NP sp rate, INT New Part Cap Inv $,
0,:NA:,:NA:,:NA:,:NA:)
* million dollars
* The capital investment for new part.

NP sp rate = New Part Cap Inv $ / 4
* million dollars/week
* This takes into account the time it takes to actually invest the money in new parts and improve operations.

NPV Income = SINTEG(Chg income, INT NPV Income,0,:NA:,:NA:,:NA:,:NA:)
* million dollars
* This is the calculation of the NPV income for a model run. It is used for comparing different options to take into account the discounting of future operations.
*:SUPPLEMENTARY

shareholder's equity = Retained Earnings + Total Equity
* million dollars

****
E. Internal finance 3(view 61)
****

ATOI = ATOI new
* million dollars/year
* After tax operating income excluding maintenance inspections.

ATOI new = (capacity online / 100) * DR power rating * rate per kwh / 1e+006
* million dollars/year

bought pow cost = (bought power / 100) *DR power rating * 168 * 1000 * (DR bought pow rat / 1e+006) * 1.2
* million dollars/week
* This is the cost of buying electricity from other utilities.

INT working cap = - Book Investment + (100 * (ATOI + depreciation)) / init CROI

Working Cap = INTEG(0, INT working cap)
* million dollars
* Investment in working capital.

init CROI = 12
* percent/year
* Initial cash return on investment.

DR bought pow rat = 0.07
* dollars/kwh
* This is the cost of buying electricity wholesale. It is higher than the total cost of producing it.

O and M costs = forced shutdown cost + ops + labor cost + lawsuit cost + maint parts cost + week fix cost + bought pow cost +DR dollar on education + max bud lobby +NRC insp cost
* million dollars/part
* Operations and Maintenance costs. Total spending on day to day genaration of power.

DR cost per lawsuit = 1
* million dollars
* Cost per interest group lawsuit.

CROI = 100 * (Investment * 52 / total investment)
* percent/year
* Cash return on investment.
*:SUPPLEMENTARY

debt payments = (U internal rate of return / 52 * (1+ U internal rate of return/52)^(30*52)) / ((1+U internal rate of return/52)^(30*52)-1) * (-Debt)
* million dollars/week
* Debt payments. These are the weekly payments to lower debt.

forced shutdown cost = EFF Forced Outage *1
* million dollars
* Cost of each shutdown.

fuel costs = (capacity utilization / 100) * (DR power rating*168) * (DR unit $ fuel + DR HL waste mgt)
* million dollars/week
* The fuel cost based on capacity.

DR HL waste mgt = 5 / 1e+006
* million dollars/ MW-hr
* Waste management cost. Waste MGT cost is calculated based on the amount of waste generated. It depends on amount of fuel burned thus a $/MW-hr figure used.

labor cost = cost mech labor + cost non mech labor
* million dollars/week
* Labor cost

lawsuit cost = (Suit filing rate / 100) * DR cost per lawsuit
* million dollars/week
* Lawsuit costs. This is the price of lawsuits brought by anti - nuclear groups.

maint parts cost = Dollar deliveries
* million dollars/week
* This is total spending parts.

ops = (DR ops overhead * capacity utilization / 100) + fuel costs
* million dollars/week
* This is the total cost of operating the rx based on capacity.

DR ops overhead = 0.5
* million dollars/week
* This is additional costs incurred in operations such as janitorial services, some paperwork.

total investment = Book Investment + Working Cap

DR unit $ fuel = ((0.005 * 1000) /1e+006)
* million dollars /Mwe-hr
* This reflect 0.5cent/kw-hr *1000 to change to Mw-hrs/1E6 to change to millions of dollars.

****

E. Internal finance 4(view 62)

****

maint cost per ERV = 100 * (annual materials cost + maint labor cost) / DR replacement investment
*:SUPPLEMENTARY

bought eq cap inv$ = max bud parts * cap inv mult * 0.1
* million dollars
* Bought equipment capital investment dollars. This is the amount of money the utility wishes to spend outright on new equipment outright instead of fixing it in the PMS system. In return the time down is assumed to be a small fraction of PMS and the defects due to operations are assumed to go down with new equipment.

capital costs = Cptl imp cash + bought eq cap inv$
* million dollars/week
*:SUPPLEMENTARY

cost mech labor = ((Mstaff avail mech work + total insp manpower) * (DR standard hours + Ave Overtime) * DR hrly cost labor * DR mech experience cost factor) * D overhead eff
* million dollars/week
* Cost mechanical labor.

cost non mech labor = (planners maint * (DR standard hours + Ave Overtime) * DR hrly cost labor + ((total engineers / EFF REG ABAND TOT ENG and MGR) * (cost of eng OT + (DR eng annual salary / 52)) + (DR mgr annual salary * (total managers / EFF REG ABAND TOT ENG and MGR) / 52))) * D overhead eff
* million dollars/week
* Cost non-mechanical labor.

DR cost per insp = 0.02
* million dollars/week
* This is the cost per week of having NRC inspection.

DR eng annual salary = 50000 / 1e+006
* million dollars/year
* This is the allocated average salary for engineers.

DR hrly cost labor = (30.59)/1e+006
* million dollars/hour
* Originally yearly cost mechanic(million dollars/year)=4.25/91(the yearly labor cost at the ADN area at Sabine is 4.25 million $.) Changing to hourly cost of maintenance personnel so as to account for increasing cost of overtime, etc.

maint labor cost = (cost mech labor+cost non mech labor) * 52
* million dollars/year

NRC insp cost = DR cost per insp * NRC Investigation in Progress
* million dollars/week
* Cost of NRC inspection : salaries of NRC personnel, material costs supporting the local office. It does not include the utility labor cost incurred.

D overhead eff = 1.3

****

E. Internal finance 5(view 63)

****

init AMC = INITIAL(annual materials cost)
init CO = INITIAL(capacity online)
init MLC = INITIAL(maint labor cost)

INT ATOI ex Maint = ATOI + maint labor cost + annual materials cost

INT NPV Costs = 0
* million dollars
* The initial value of NPV costs.

INT NPV Downtime = 0
* million dollars
* The initial value of NPV downtime.

DR annual fixed costs =40
* million dollars/year
* Annual fixed cost.

annual materials cost = Maint materials cost * 52
* million dollars/year

ATOI ex Maint =INTEG(0, INT ATOI ex Maint)
* After tax operating income excluding maintenance cost. This includes fuel costs. No it doesn't.

capacity utilization = MIN(PLANT DEMAND, 100-downtime PCT)
* percentage
* This is the maximum actual capacity required by the plant.

Chg NPV costs = (init MLC + init AMC - maint labor cost - annual materials cost) * discount factor / 52

Chg NPV downtime = downtime CF * discount factor / 52
* million dollars/week

cost downtime per PCT = (ATOI ex Maint + depreciation + DR annual fixed costs * 0.66 - maint labor cost - annual materials cost) / (100 - expect downtime PCT)
* million dollars/downtime percent
* Downtime cost per percentage point of downtime.

downtime CF = IF THEN ELSE(PLANT DEMAND>=(100-downtime PCT), cost downtime per PCT*(expect downtime PCT-downtime PCT), 0)
* Cash flow cost of downtime.

downtime PCT = capacity down
* percentage
* Percentage of capacity down.

expect downtime PCT =100 - init CO
* percentage
* Expect downtime percentage.

Maint NPV = NPV Downtime + NPV Costs
* million dollars
*:SUPPLEMENTARY

NPV Costs = INTEG(Chg NPV costs, INT NPV Costs)
* million dollars
* NPV of decrease or increase in maintenance cost above or below the initial conditions.

NPV Downtime = INTEG(Chg NPV downtime, INT NPV Downtime)
* million dollars
* Net present value cost of downtime above or below the initial level of down time.

PLANT DEMAND = F Plant demand(weeks)
* percentage
* Product demand as a percent of capacity.

week fix cost = DR annual fixed costs / 52
* million dollars/week
* This is the cost maintaining the plant, grounds and bus equipment. It is the same whether or not the plant produces electricity.

weeks = Time

****
E. PUC 1(view 64)
****

eviliness = D evil amount * (0 + STEP(evil puc fun, 100))
* hades
* This is in the utility's view, a measure of how much the PUC suddenly reduces the rate of return. It is not dependent on any outside variables and can change based on PUC political changes.

PUC ch RB = - EFF PUC RB * (Rate Base / INT Rate Base) / D rate base decision delay
* million dollars/week
* This is the change in rate base determined only by the PUC's decision to disallow additions to the rate base.

INT Rate Base =INT Book Investment
* million dollars
* The initial value of Rate Base.

INT PUC Perceived Prudence = 0.4
* unit of prudence
* The initial value of PUC perceived prudence.

allowed ROE = (cost of capital -1) * EFF PUC ROE * (1 - eviliness)
* percentage
* This is the allowed return on ratebase proposed as derived from the PUC's perceived prudence.

Chg perc prud = ((current ind prud - PUC Perceived Prudence) / delay adj PP)
* unit of prudence/week
* Change in perceived prudence.

Con cap inv = Investment
* million dollars/week
* This is the total investment in the utility.

current ind prud = EFF SP PUC * EFF REL CAPACITY FRCST * EFF BR PUC *EFF CUS PUC * EFF PS PUC * EFF PI PUC * (1 - eviliness)
* unit of prudence
* Current indicator of prudence. This is the product of all of the factors which influence the PUC's perceived view of how the utility management is running the plant.

customer satisfaction = D system reliability * EFF LPO CUS SAT * EFF CPRCS
* dimensionless
* This is the product of the three factors which influence customer satisfaction.

Decomm = Dep XA
* million dollars/week
* This is how depreciation of plant flows out of the rate base.

delay adj PP = MAX((current ind prud * EFF PS PUC) / PUC Perceived Prudence, 52)
* weeks
* Delay in adjusting perceived prudence.

EFF REL CAPACITY FRCST =F EFFCaprel frcst(((capacity utilization / 100) + 0.8 * Periodic Outage) / D for cap)
* dimensionless
* Effect of capacity relative to forecast. This is the negative or positive effect on the PUC of the utility correctly predicting its capacity factor.

EFF CUS PUC =F EFFCUSPUC(customer satisfaction)
* dimensionless
* Effect of customer satisfaction on PUC.

EFF PUC RB =F EffPUCRB(PUC Perceived Prudence)
* dimensionless
* Effect of the PUC's perceived prudence on the rate base.

EFF PUC ROE = F EFFPucROE(PUC Perceived Prudence)
* percent/prude
* Effect on PUC on Return on Equity. This is the effect on the fair rate of return the PUCs attitude toward the utility is.

D evil amount = 0.055
* dimensionless
* This is the percentage reductions in ROE the change in PUC political makeup has on the utility.

evil puc fun = 0
* dimensionless
* 1 turns evil PUC on, 0 is a benevolent PUC to the utility.

D for cap = 0.8

PUC Perceived Prudence = SINTEG(Chg perc prud. INT PUC Perceived Prudence,0,:NA:,:NA:,:NA:,:NA:)

* unit of prudence
* This is the Public Utilities Commission's decision to reward or punish the utility. Several completing factors work to raise or lower the utility's ROE. If the utility is operating safety the PUC will reward it. If it is looked at kindly in the financial markets it will also reward it respecting the opinions of advisors.
  However if the utility makes too much money, the PUC will realize it is rewarding it too much so will lower the return of equity. Likewise if the utility is really hurting it will increase the ROE.

Rate Base = SINTEG(Con cap inv-Decomm-PUC ch RB, INT Rate Base,0,:NA:,:NA:,:NA:,:NA:)

* million dollars
* Dollar amount of capital which the PUC decide to include in determining rate of return.

D rate base decision delay = 52

* weeks
* This is the time is normally takes to determine a rate base decision.

D system reliability = 0.995

* dimensionless
* It represents the capacity relative to demand not made up for by purchased power.

****

E. PUC 2(view 65)

****

markup = IF THEN ELSE((current yr costs / est yr rev < 1),1,(current yr costs + bud div * 52) / est yr rev)

* dimensionless
* The utility adds on some extra requirements for income if it has not received enough award in the past from the PUC.

INT PUC Rate = 0.055

* dollars
* The initial value of PUC rate.

all rate = ((((allowed ROE / 52) * Rate Base) +(utility req total * (1 - eviliness) * (test yr $ pct kwh / est yr cost per kwh)) + pass through) * 1e+006) / (DR power rating * 1000 * 168)

* cent/kwh
* This is the average cost per kwh indicated by the PUC's decision standard. Allowed ROE / 5200 + 1

Chg PUC rate = (all rate - PUC Rate) / PUC delay

* dollars/week
* Change in PUC allowed rate.

competition rate = (0.05 + (1 - competition switch) * 0.05) + (- 0.001 * RAMP(0.05, 100, 1000) + 0.001 * RAMP(0.05, 300, 1000)) * competition switch

* dimensionless
* This is the rate a competitor is charging. The utility must come close to matching this rate or lose customers. In the model the utility automatically makes it's price 1.1 * Comp rate.

competition switch = 0

current yr costs = SMOOTH((Costs + Taxes) * 52 * 1e+006, 13)
* million dollars/week
* This is the total weekly costs averaged over the past year.

current yr MW sales = SMOOTH(((capacity utilization + bought power) / 100) * DR power rating * 52 * 1000 *168, 13) + 1
* Megawatts
* This is the estimated number of megawatts the utility believes it will sell this year.

EFF PUC StRISK =F EFFPUCStRisk(PUC aggreability)
* dimensionless
* Effect of PUC aggreability on stock. A graph of the effect from the previous allowed ROE on the stock price.

est yr cost per kwh = current yr costs / current yr MW sales
* dollars/kwh
* This is the predicted future rate requirements to make up for costs based on the last year's performance.

est yr rev = SMOOTH(Revenues * 52 *1e+006, 52) + 1e+006
* million dollars/week
* This is the average weekly revenues averaged over the last year to determine if the utility believes it will have a shortfall in which case it will markup its request.

pass through = O and M
* million dollars/week
* Pass through costs. This is the rate portion that rate payers automatically pay for.

DR power rating = 1000
* kwh
* This is the number of kwh generated per time period to determine revenues.

PUC aggreability = PUC Rate / utility req total
* dimensionless
* This is the ratio of the utility's requested rate to the PUC's awarded rate. It is a measure of how financial institutions rate whether the utility will receive future rate hikes.

PUC delay = ((all rate / (PUC Rate + 0.0001)) * 26) + 8

PUC Rate = SINTEG(Chg PUC rate, INT PUC Rate,0,:NA:,:NA:,:NA:,:NA:)
* dollars
* PUC rate. This is the maximum average computed legal rate the utility may be charged based on the utility's fair rate of return.

O and M = ops

rate per kwh = MAX(MIN(competition rate * 1.1, PUC Rate), 0.01)
* dollars/kwh
* This is the rate in dollars per kilowatt hour on average for the electricity the nuclear plant self's. It is , in effect, just allowed revenue/net power produced.

utility req total = SMOOTH3(markup * (Costs + Taxes - ops), 26)
* million dollars/week
* This is the utility presented revenue requirement minus pass through.

****

E. PUC 3(view 66)

****

init R = INITIAL(Revenues)
init CU = INITIAL(capacity utilization)
init PR = INITIAL(DR power rating)

INT Ave Utility Rate = 0.055
  * dollars
  * The initial value of average utility rate.

INT Customer Perceived Relative Rate = 1
  * dimensionless
  * The initial value of customer perceived relative rate.

Chg cus per rate = (relative rate - Customer Perceived Relative Rate) / delay rate

Ave Utility Rate = SINTEG(Rate change, INT Ave Utility Rate,0,:NA:,:NA:,:NA:,:NA:)
  * dollars
  * Average utility rate. This is the typical utility rate in the area around the customer which he uses to compare his utility bill to.

Customer Perceived Relative Rate = SINTEG(Chg cus per rate, INT Customer Perceived Relative Rate,0,:NA:,:NA:,:NA:,:NA:)
  * dimensionless
  * Customer Perceived Relative Rate. This takes into account the time delay of receiving the bills and checking out inflation etc.

delay rate = (Customer Perceived Relative Rate / relative rate) * 4
  * weeks
  * This is the delay from enactment that a change in rates starts to affect customer perception. For minor changes it is the time it takes him to get the bill. For increases it gets shorter since the newspapers will invariably cover them.

EFF CPRCS =F EFFCPRCS(Customer Perceived Relative Rate)
  * dimensionless
  * Effect of customer perceived relative rate on customer satisfaction.

Rate change = (inflation rate / 52 * TIME STEP) * Ave Utility Rate

relative rate = rate per kwh / Ave Utility Rate
  * dimensionless
  * This is the ratio of the utility's rate to the average rate in the area to determine how angry the customers are.

test yr $ pct kwh = test yr rev / test yr sales
  * dollars/kwh
  * This is the average cost of electricity during an average year picked by the PUC.

test yr rev =init R * 52 * 1e+006
  * million dollars/week
  * This is the total average dollars earned per week in an average year picked by the PUC.

test yr sales =init CU / 100 * init PR * 52 * 1000 *168
* million dollars
* Based on a previous operating year, usually switched every years or so, the average revenues of the utility are determined to see how much money the utility would normally earn and to budget costs.

****

E. Stock 1(view 69)

****

init ASP = INITIAL(actual share price)

D desired DE ratio = 1

INT Market Value per Share stable = init stock pr + 25
* The initial value of MV per Share stable.

beta debt = 0.2 * EFF BR STOCK
* dimensionless

init stock pr = ((INT Book Investment * 1e+006) / INT Shares) * (1 / (D desired DE ratio + 1)) * 0 + 3

actual share price = Market Value per Share Stable * market effects
* dollars
* Actual share price. This is the measure of assets-debt to determine the capital the utility owns outright. These assets are claimed by the shareholders.

analysis utility risk = EFF DE StRISK * EFF NPO StRISK * EFF PS StRISK * EFF PUC StRISK * EFF LPO StRISK
* dimensionless
* This is the required return by utility based on risk as perceived by analysts relative to S&P 500.

BETA AST =F Beta AST(analysis utility risk)
* dimensionless
* Beta is a measure of volatility and risk relative to the stock market. If analysis's utility risk is 1 and interest rate is 0.04 then beta will be 1.

beta equity = BETA AST + ((BETA AST - beta debt) * DE ratio)
* dimensionless
* This is the relative risk of investing in utility stock. The equation comes from pg. 186 of ref 1. (Brealey: Princ of Corp Finance) 1987.

cost of capital = stock discount rate + 1
* percentage
* This is the average cost of obtaining equity or borrowing for the utility. The PUC uses it to determine a fair rate of return.

delay in adj MV = (0.2 * ind of market value / Market Value per Share Stable) + 0.01

dividend forecast = ((SMOOTHI(Dividends, 52, 1)) * 1e+006) / Shares

DT market value = ((ind of market value - Market Value per Share Stable) / delay in adj MV) / 100

EFF DE StRISK =F EFFDEStRisk(DE ratio)
* dimensionless

EFF SP PUC =F EFFSPPUC(actual share price / init ASP)
* dimensionless
* Effect of stock price on PUC. If the SP of the utility falls too much the PUC will look kindly on the utility. Or if it rises too fast, it will reduce the ROE.

expected growth = allowed ROE
* The expected growth determined by a forecast.

ind of market value = MAX(dividend forecast / (relative growth), 0.005)
* Indicator of market value is the result of dividend forecast and Beta for the utility or relative required return based on the risk of the investment compared to the return on bonds. If interest rates rise the relative return from utilities fall and the stock price because utility stocks are dividend stocks and not growth stocks.

Market Value per Share Stable = SINTEG(DT market value, INT Market Value per Share stable,0,:NA:,:NA:,:NA:,:NA:)
* Market value per share stable.

relative growth = MAX(MIN(stock discount rate - expected growth, 0.5), 0.01)

stock discount rate = SMOOTH(D T bill rate + (beta equity * (DR stock mkt SS - D T bill rate)), 3)

DR stock mkt SS = 0.1

D T bill rate = 0.0535
* dimensionless
* This is the one year treasure bill rate when starting the run of the model. Must be inserted by the user.

****
E. Stock 2(view 70)
****

INT Shares = 800000
* shares
* The initial value of Shares.

INT Total Equity = assets - Debt

desired number of shares to sell = (desired new equity * 1e+006) / actual share price

book value per share = ((assets - Debt) / Shares) * 1e+006

Chg total equity = equity raised

desired new equity = IF THEN ELSE((net cash flow<0), (ABS(net cash flow) + Taxes) * D equity factor * EFF MBRDNE, 0)

EFF MBRDNE =F EFFMBRDNE(market to book ratio)
* dimensionless

D equity factor = 0.4

equity raised = actual share price * Share issue rate / 1e+006
* million dollars

market to book ratio = actual share price / book value per share
* dimensionless

Share issue rate = desired number of shares to sell / DR time to sell shares
* shares/week

Shares = SINTEG(Share issue rate, INT Shares,0,:NA:,:NA:,:NA:,:NA:)
* shares
* Number of shares total.

DR time to sell shares = 1
* weeks
* Time to sell share.

Total Equity = SINTEG(Chg total equity, INT Total Equity,0,:NA:,:NA:,:NA:,:NA:)
* million dollars
* This is the measure of assets-debt to determine the capital the utility owns outright. These assets are claimed by the shareholders.

F. Simulation Control Parameters

FINAL TIME = 520
* week
* The final time for the simulation.

INITIAL TIME = 0
* week
* The initial time for the simulation.

SAVEPER = TIME STEP
* week
* The frequency with which output is stored.

TIME STEP = 0.25
* week
* The time step for the simulation

G. Subscripts

XCorrective Action : PRO, MOD, TRA
XLearning and Training : WO, BE, DR, OE, IN, FO
XPublic Concern : NA, LO
XProb Reporting : VEN, NRC, EPR, WAN
XSched Work Order : S1, S2, S3, S4, S5
XUnschd Work Order : U1,U2, U3, U4

H. Lookup Functions

F Beta AST ([(0,0.2)-(2,0.6)],(0,0.208),(0.2,0.212),(0.4,0.22)
,(0.6,0.228),(0.8,0.242),(1,0.264),(1.2,0.286),(1.4,0.322),(1.6,0.364)
,(1.8,0.422),(2,0.598))

F Bond Rating ([(0,0)-(100,20)],(0,0.18),(11.109,0.18),(11.11,2.82)
,(22.219,2.82),(22.22,4.08),(33.329,4.08),(33.33,4.92),(44.439,4.92)
,(44.44,6.78),(55.559,6.78),(55.56,8.16),(66.669,8.16),(66.67,9.18)
,(77.779,9.18),(77.78,10.38),(88.889,10.38),(88.89,11.64),(100,11.64))

F event occurances ([(0,0)-(1,8)],(0,1),(0.05,1),(0.1,1),
(0.15,1),(0.2,1),(0.25,1),(0.3,1),(0.349999,1),(0.35,2),(0.4,2)
,(0.45,2),(0.5,2),(0.549999,2),(0.55,3),(0.6,3),(0.649999,3)
,(0.65,4),(0.7,4),(0.75,4),(0.7999,4),(0.8,5),(0.85,5),(0.9,5)
,(0.949999,5),(0.95,6),(1,6))

F CurIndPerSaf ([(0,0)-(2.2,100)],(0,0),(0.22,5),(0.44,30)
,(0.66,40),(0.88,55),(1.1,65),(1.32,80),(1.54,95),(1.76,99),
(1.98,99),(2.2,100))

F Delay in adj Saf perc ([(-100,0)-(100,300)],(-100,13.5)
,(-80,15),(-60,18),(-40,18),(-20,21),(0,39),(20,52),(40,78),
(60,104),(80,117),(100,129))

F EFFPSPUC G ([(0,0)-(100,1.1)],(0,0.983),(5,0.3),(10,0.2)
,(15,0.281),(20,0.322),(25,0.344),(30,0.367),(35,0.398),(40,0.425)
,(45,0.443),(50,0.466),(55,0.501),(60,0.55),(65,0.65),(70,0.7)
,(75,0.75),(80,0.8),(85,0.85),(90,0.9),(95,0.95),(100,1.1))

F EffOpsLPO ([(0,0.9)-(100,1.7)],(0,1.692),(10,1.492),(20,1.325)
,(30,1.297),(40,1.093),(50,1.053),(60,1.03),(70,1.01),(80,0.98)
,(90,0.95),(100,0.903))

F schd wait time by prod ([(0,0)-(2,5)],(0,0.25),(0.2,0.31)
,(0.4,0.6),(0.6,0.95),(0.8,1.35),(1,2),(1.2,2.7),(1.4,3.7),(1.6,4.4)
,(1.8,4.8),(2,5))

F EFF eng wo rt def ([(0,0.903)-(5,1.1)],(0.5,0.903),(0.95,0.929)
,(1.4,0.961),(1.85,0.982),(2.3,1.004),(2.75,1.032),(3.2,1.055)
,(3.65,1.075),(4.1,1.09),(4.55,1.098),(5,1.1))

F EFFOpsPS ([(0,0.9)-(100,1.1)],(0,0.948),(10,0.952),(20,0.957)
,(30,0.96),(40,0.963),(50,0.968),(60,0.975),(70,0.989),(80,1.001)
,(90,1.011),(100,1.021))

F EffBRPUC ([(0,0.991)-(12,1.01)],(0,1.01),(1.2,0.998),(2.4,0.993)
,(3.6,0.991),(4.8,0.992),(6,0.993),(7.2,0.995),(8.4,0.997),(9.6,1)
,(10.8,1.005),(12,1.008))

F EFFBRStock ([(0,0.951)-(12,1.09)],(0,1.089),(1.2,1.065),
(2.4,1.043),(3.6,1.017),(4.8,1),(6,0.981),(7.2,0.966),(8.4,0.956)
,(9.6,0.952),(10.8,0.951),(12,0.951))

F EFFLPOLPI ([(0,0.95)-(100,1.2)],(0,0.95),(10,0.969),(20,0.993)
,(30,1.001),(40,1.017),(50,1.043),(60,1.064),(70,1.094),(80,1.134)
,(90,1.171),(100,1.198))

F Mgr Layoffs from Workload ([(0,0)-(0.5,0.403)],(0,0.403)
,(0.071,0.243),(0.143,0.115),(0.214,0.078),(0.286,0.06),(0.357,0.038)
,(0.429,0.02),(0.5,0))

F EFFSRPS ([(1,0.8)-(4,1.2)],(1,1.198),(1.3,1.174),(1.6,1.148)
,(1.9,1.106),(2.2,1.056),(2.5,0.98),(2.8,0.908),(3.1,0.856),
(3.4,0.832),(3.7,0.812),(4,0.8))

F EFFPOCussat ([(0,0.802)-(100,1.122)],(0,1.122),(10,1.06)
,(20,1),(30,0.938),(40,0.886),(50,0.864),(60,0.854),(70,0.846)
,(80,0.842),(90,0.826),(100,0.802))

F EFFPOLM ([(0,0.7)-(50,1.3)],(0,0.7),(5,0.9),(10,1),(15,1.03)
,(20,1.04),(25,1.06),(30,1.12),(35,1.21),(40,1.25),(45,1.28)
,(50,1.3))

F EFFPOLPO ([(0,0.9)-(100,1.1)],(0,0.9),(10,0.904),(20,0.916)
,(30,0.933),(40,0.949),(50,0.96),(60,0.982),(70,0.995),(80,1.029)
,(90,1.076),(100,1.098))

F EFFPOM ([(0,0.8)-(50,1.3)],(0,0.8),(5,1),(10,1.012),(15,1.03)
,(20,1.066),(25,1.12),(30,1.18),(35,1.234),(40,1.273),(45,1.291)
,(50,1.3))

F Eff Mt wo rt def ([(0,0.9)-(5,1.1)],(0.5,0.9),(0.95,0.932)
,(1.4,0.963),(1.85,0.987),(2.3,1.004),(2.75,1.032),(3.2,1.055)
,(3.65,1.077),(4.1,1.089),(4.55,1.096),(5,1.099))

F EFFPOPI ([(0,1)-(50,1.3)],(0,1),(5,1.04),(10,1.08),(15,1.12)
,(20,1.15),(25,1.19),(30,1.23),(35,1.27),(40,1.3),(45,1.3),(50,1.3))

F EFFPOStRisk ([(0,0.98)-(100,1.07)],(0,0.981),(10,0.99),(20,0.999)
,(30,1.004),(40,1.009),(50,1.018),(60,1.025),(70,1.034),(80,1.046)
,(90,1.055),(100,1.066))

F EFFPSFM ([(-20,-30)-(20,5)],(-20,-30),(-16,-21.77),(-12,-15.12)
,(-8,-6.9),(-4,-2.525),(0,0),(4,1.675),(8,2.725),(12,3.425),
(16,4.3),(20,5))

F EFFPSPUC E ([(0,0.2)-(100,1.08)],(0,0.2),(10,0.205),(20,0.205)
,(30,0.335),(40,0.43),(50,0.511),(60,0.601),(70,0.7),(80,0.8)
,(90,0.95),(100,1.08))

F frac equip dfct mand insp ([(0,0)-(1,1)],(0,0),(0.1,0.15)
,(0.2,0.3),(0.3,0.435),(0.4,0.55),(0.5,0.65),(0.6,0.745),(0.7,0.83)
,(0.8,0.91),(0.9,0.965),(1,1))

F EFFPSStRisk ([(0,0.96)-(100,2)],(0,1.555),(10,1.551),(20,1.506)
,(30,1.39),(40,1.289),(50,1.208),(60,1.121),(70,1.054),(80,1.009)
,(90,0.96),(100,0.96))

F EFF uw Ert Def ([(0,0.901)-(5,1.1)],(0.5,0.901),(0.95,0.949)
,(1.4,0.988),(1.85,1.013),(2.3,1.034),(2.75,1.048),(3.2,1.061)
,(3.65,1.071),(4.1,1.081),(4.55,1.092),(5,1.1))

F EffUtGoodwillLPO ([(0,0.95)-(3,1.08)],(0,1.078),(0.103,1.073)
,(0.207,1.07),(0.31,1.064),(0.414,1.051),(0.517,1.044),(0.621,1.037)
,(0.724,1.023),(0.828,1.017),(0.931,1.001),(1.034,0.993),(1.138,0.975)
,(1.241,0.968),(1.345,0.964),(1.448,0.963),(1.552,0.961),(1.655,0.961)
,(1.759,0.96),(1.862,0.959),(1.966,0.951),(2.069,0.958),(2.172,0.958)
,(2.276,0.958),(2.379,0.957),(2.483,0.957),(2.586,0.957),(2.69,0.955)
,(2.793,0.953),(2.897,0.952),(3,0.95))

F EFFuwoMrtdef ([(0.5,0.901)-(5,1.1)],(0.5,0.901),(0.95,0.97)
,(1.4,1.019),(1.85,1.046),(2.3,1.07),(2.75,1.084),(3.2,1.093)
,(3.65,1.097),(4.1,1.098),(4.55,1.099),(5,1.099))

F eff prod pres on OT ([(1,0)-(1.5,2)],(1,0),(1.042,0.408),
(1.083,0.732),(1.125,0.948),(1.167,1.098),(1.208,1.26),(1.25,1.42)
,(1.292,1.56),(1.333,1.68),(1.375,1.77),(1.417,1.85),(1.458,1.94)
,(1.5,2))

F EFFLPOGW ([(0,0.8)-(100,1.2)],(0,1.2),(10,1.152),(20,1.116)
,(30,1.084),(40,1.06),(50,1.03),(60,1.002),(70,0.974),(80,0.916)
,(90,0.846),(100,0.802))

F Ind of Credit PFS ([(1,0)-(4,100)],(1,1.5),(1.3,3),(1.6,5)
,(1.9,8.5),(2.2,16),(2.5,35.5),(2.8,54),(3.1,80.5),(3.4,95.5)
,(3.7,97),(4,100))

F EFFSPPUC ([(0,0)-(40,1.1)],(0,1.1),(1.379,0.97),(2.759,0.61)
,(4.138,0.325),(5.517,0.225),(6.897,0.18),(8.276,0.145),(9.655,0.135)
,(11.03,0.14),(12.41,0.135),(13.79,0.13),(15.17,0.125),(16.55,0.12)
,(17.93,0.12),(19.31,0.125),(20.69,0.135),(22.07,0.115),(23.45,0.1)
,(24.83,0.1),(26.21,0.1),(27.59,0.1),(28.97,0.1),(30.34,0.1)
,(31.72,0.1),(33.1,0.1),(34.48,0.1),(35.86,0.1),(37.24,0.1),
(38.62,0.1),(40,0.1))

F EFFLPOM ([(0,0.99)-(100,1.093)],(0,0.99),(10,0.992),(20,0.993)
,(30,0.993),(40,0.994),(50,0.993),(60,0.994),(70,0.995),(80,0.996)
,(90,1.012),(100,1.093))

F EFFLPOStRisk ([(0,0.934)-(100,1.1)],(0,0.934),(10,0.938)
,(20,0.941),(30,0.974),(40,0.995),(50,1.015),(60,1.059),(70,1.075)
,(80,1.085),(90,1.094),(100,1.098))

F EFFFOPS ([(0,0.95)-(1,1)],(0,0.999),(0.1,0.988),(0.2,0.981)
,(0.3,0.976),(0.4,0.973),(0.5,0.97),(0.6,0.966),(0.7,0.961),
(0.8,0.957),(0.9,0.954),(1,0.951))

F New Eng Hiring from OT ([(1,0)-(4,1.97)],(1,0.05),(1.333,0.08)
,(1.667,0.13),(2,0.25),(2.333,0.42),(2.667,0.66),(3,1.31),(3.333,1.72)
,(3.667,1.9),(4,1.97))

F New Mgt Hiring from OT ([(1,0)-(4,1.5)],(1,0),(1.333,0.218)
,(1.667,0.405),(2,0.585),(2.333,0.788),(2.667,0.998),(3,1.163)
,(3.333,1.313),(3.667,1.425),(4,1.485))

F Eng Layoffs from OT ([(0,0)-(1,1.5)],(0,1.493),(0.111,0.518)
,(0.222,0.308),(0.333,0.21),(0.444,0.12),(0.556,0.083),(0.667,0.038)
,(0.778,0.03),(0.889,0),(1,0.008))

F Event Effect ([(0,0.75)-(1,1)],(0,0.999),(0.1,0.979),(0.2,0.953)
,(0.3,0.915),(0.4,0.881),(0.5,0.856),(0.6,0.834),(0.7,0.809)
,(0.8,0.794),(0.9,0.775),(1,0.75))

F EFFNRCinvMGTENG ([(0,0.6)-(5,1)],(0,0.998),(0.5,0.996),
(1,0.981),(1.5,0.948),(2,0.908),(2.5,0.846),(3,0.752),(3.5,0.692)
,(4,0.64),(4.5,0.618),(5,0.602))

F frac equip dfct dsc insp ([(0,0)-(1,1)],(0,0),(0.1,0.15)
,(0.2,0.3),(0.3,0.435),(0.4,0.55),(0.5,0.65),(0.6,0.745),(0.7,0.83)
,(0.8,0.91),(0.9,0.965),(1,1))

F schd recycle time ([(0,0.5)-(2,4)],(0,4),(0.167,3.54),(0.333,3.06)
,(0.5,2.54),(0.667,2.04),(0.833,1.6),(1,1.25),(1.167,1.02),(1.333,0.88)
,(1.5,0.76),(1.667,0.68),(1.833,0.58),(2,0.5))

F EFFLPOPerSaf ([(0,0.901)-(100,1.1)],(0,1.1),(10,1.008),(20,0.994)
,(30,0.993),(40,0.992),(50,0.988),(60,0.989),(70,0.981),(80,0.975)
,(90,0.945),(100,0.901))

F EFFMBRDNE ([(0,0)-(5,2)],(0,0.01),(0.5,0.35),(1,0.623),(1.5,0.84)
,(2,1.035),(2.5,1.254),(3,1.453),(3.5,1.612),(4,1.741),(4.5,1.851)
,(5,1.99))

F frac rtrnd given dfct ([(0,0)-(100,0.32)],(0,0),(10,0.018)
,(20,0.04),(30,0.065),(40,0.105),(50,0.17),(60,0.225),(70,0.27)
,(80,0.3),(90,0.315),(100,0.32))

F EFFLREX ([(0,0.904)-(100,1.04)],(0,0.904),(10,0.904),(20,0.907)
,(30,0.917),(40,0.942),(50,0.991),(60,1.02),(70,1.03),(80,1.04)
,(90,1.04),(100,1.04))

F EFFPOPerSaf ([(0,0.925)-(10,1.21)],(0,1.21),(1,1),(2,0.997)
,(3,0.982),(4,0.967),(5,0.961),(6,0.955),(7,0.946),(8,0.94),
(9,0.931),(10,0.925))

F EFFDEStRisk ([(0,0.99)-(5,1.13)],(0,0.992),(0.5,1),(1,1)
,(1.5,1),(2,1.004),(2.5,1.008),(3,1.012),(3.5,1.016),(4,1.024)
,(4.5,1.054),(5,1.126))

F EFFUOpsPO ([(0,0.976)-(1,1.021)],(0,1.021),(0.1,1.012),(0.2,1.009)
,(0.3,1.006),(0.4,1.006),(0.5,1.003),(0.6,1),(0.7,0.991),(0.8,0.982)
,(0.9,0.976),(1,0.976))

F EffEBFO ([(0,0)-(0.5,10)],(0,0),(0.025,0),(0.05,0.125),(0.075,0.125)
,(0.1,0.25),(0.125,0.35),(0.15,0.35),(0.175,0.35),(0.2,0.4),
(0.225,0.65),(0.25,1.3),(0.275,1.85),(0.3,2.55),(0.325,3.45)
,(0.35,4.45),(0.375,5.35),(0.4,6.2),(0.425,6.9),(0.45,7.6),(0.475,8.4)
,(0.5,9.8))

F EFFCLM ([(0,0)-(250,2)],(0,1),(25,1.02),(50,1.05),(75,1.07)
,(100,1.1),(125,1.12),(150,1.15),(175,1.17),(200,1.2),(225,1.22)
,(250,1.25))

F EFFCLNRC ([(0,0)-(200,2)],(0,0.7),(25,1),(50,1.03),(75,1.04)
,(100,1.05),(125,1.07),(150,1.1),(175,1.15),(200,1.21),(225,1.26)
,(250,1.3))

F EFFCUSPUC ([(0,0.2)-(1.1,1.1)],(0,0.214),(0.1,0.569),(0.2,0.664)
,(0.3,0.731),(0.4,0.749),(0.5,0.753),(0.6,0.767),(0.7,0.785)
,(0.8,0.83),(0.9,0.916),(1,1),(1.1,1.097))

F EffCussatGW ([(0,0.901)-(1,1.097)],(0,0.901),(0.1,0.907)
,(0.2,0.912),(0.3,0.927),(0.4,0.941),(0.5,0.953),(0.6,0.981)
,(0.7,1.051),(0.8,1.078),(0.9,1.093),(1,1.097))

F EFFGAPO ([(0.7,0.7)-(1.3,1.3)],(0.7,1.03),(0.76,1),(0.82,1)
,(0.88,1),(0.94,1),(1,1),(1.06,0.988),(1.12,0.982),(1.18,0.979)
,(1.24,0.973),(1.3,0.955))

F EFFidprobEPRI ([(1,1)-(2,5)],(1,1.04),(1.1,1.1),(1.2,1.1)
,(1.3,1.1),(1.4,1.12),(1.5,1.16),(1.6,1.281),(1.7,1.621),(1.8,2.365)
,(1.9,3.321),(2,5))

F EFFidprobWANO ([(1,1)-(2,1.5)],(1,1),(1.1,1.013),(1.2,1.02)
,(1.3,1.02),(1.4,1.025),(1.5,1.035),(1.6,1.05),(1.7,1.088),(1.8,1.155)
,(1.9,1.298),(2,1.489))

F EFFLOBLM ([(0,0.96)-(10,1.2)],(0,1.2),(1,0.985),(2,0.979)
,(3,0.977),(4,0.974),(5,0.972),(6,0.97),(7,0.967),(8,0.965),
(9,0.965),(10,0.96))

F EffLOCEdGW ([(0,0)-(10,3)],(0,0.207),(0.714,0.519),(1.429,1.362)
,(2.143,2.034),(2.857,2.37),(3.571,2.608),(4.286,2.664),(5,2.734)
,(5.714,2.776),(6.429,2.818),(7.143,2.874),(7.857,2.93),(8.571,2.958)
,(9.286,2.958),(10,2.986))

F EFFMNRC ([(0,0.7)-(10,1.3)],(0,0.88),(1,0.949),(2,1),(3,1)
,(4,1),(5,1.006),(6,1.018),(7,1.036),(8,1.057),(9,1.108),(10,1.195))

F EFFMPO ([(0,0.7)-(30,1.3)],(0,0.862),(1.034,1.034),(2.069,1.034)
,(3.103,1.034),(4.138,1.057),(5.172,1.066),(6.207,1.078),(7.241,1.099)
,(8.276,1.126),(9.31,1.138),(10.34,1.159),(11.38,1.171),(12.41,1.195)
,(13.45,1.201),(14.48,1.219),(15.52,1.222),(16.55,1.24),(17.59,1.249)
,(18.62,1.258),(19.66,1.267),(20.69,1.27),(21.72,1.279),(22.76,1.282)
,(23.79,1.279),(24.83,1.288),(25.86,1.288),(26.9,1.288),(27.93,1.288)
,(28.97,1.291),(30,1.3))

F EFFNRCInvmlnsp ([(1,1)-(10,6)],(1,1.023),(2,1.105),(3,1.15)
,(4,1.25),(5,1.475),(6,1.825),(7,2.3),(8,2.85),(9,3.9),(10,5.975))

F EFFNRCminsp ([(1,1)-(4,6)],(1,1),(4,6))

F EFFNRCRDDIMI ([(1,1)-(6,6)],(1,1),(1.5,1.15),(2,1.325),(2.5,1.7)
,(3,2),(3.5,2.35),(4,2.7),(4.5,3.225),(5,4),(5.5,4.65),(6,5.9))

F EFFNRCrepml ([(1,1)-(2,1.7)],(1,1),(1.1,1.03),(1.2,1.12)
,(1.3,1.293),(1.4,1.383),(1.5,1.428),(1.6,1.506),(1.7,1.566)
,(1.8,1.615),(1.9,1.664),(2,1.698))

F EFFOpsNRCIn ([(0,0)-(100,0.5)],(0,0.5),(10,0.138),(20,0.05)
,(30,0.028),(40,0.013),(50,0.005),(60,0),(70,0),(80,0),(90,0)
,(100,0))

F EffOpsNRCInv ([(0,0.709)-(100,1.24)],(0,1.237),(10,1.171)
,(20,1.102),(30,1.057),(40,1.033),(50,1.018),(60,1.003),(70,1)
,(80,1),(90,0.997),(100,0.709))

F EFFPILM ([(0,0.7)-(10,1.3)],(0,0.82),(1,0.997),(2,1),(3,1)
,(4,1.006),(5,1.027),(6,1.087),(7,1.174),(8,1.246),(9,1.288)
,(10,1.297))

F EffPIM ([(0,0)-(10,0.75)],(0,0),(1,0),(2,0),(3,0),(4,0),
(5,0.01),(6,0.035),(7,0.1),(8,0.203),(9,0.409),(10,0.728))

F EFFPINRC ([(0,0.7)-(20,1.3)],(0,0.877),(2,1),(4,1),(6,1.006)
,(8,1.015),(10,1.03),(12,1.042),(14,1.06),(16,1.078),(18,1.111)
,(20,1.138))

F EFFPIPUC ([(0,0.7)-(10,1.1)],(0,0.98),(1,0.944),(2,0.898)
,(3,0.896),(4,0.894),(5,0.892),(6,0.89),(7,0.884),(8,0.792),
(9,0.748),(10,0.7))

F Plant Operations ([(0,0)-(100,4)],(0,4),(10,4),(20,4),(29,4)
,(30,4),(30,3),(40,3),(50,3),(59.999,3),(60,2),(70,2),(80,2)
,(89.999,2),(90,1),(100,1))

F Report Ratio ([(0,0)-(2,2)],(0,0.04),(0.2,0.12),(0.4,0.27)
,(0.6,0.47),(0.8,0.71),(1,1),(1.2,1.09),(1.4,1.19),(1.6,1.42)
,(1.8,1.72),(2,1.98))

F eff OT fatigue mgr ([(0,0.75)-(20,1)],(0,1),(2.222,0.98)
,(4.444,0.971),(6.667,0.958),(8.889,0.924),(11.11,0.895),(13.33,0.835)
,(15.56,0.781),(17.78,0.755),(20,0.752))

F Eff OT fatigue OA ([(0,0.72)-(20,1)],(0,0.995),(2,0.97),
(4,0.95),(6,0.925),(8,0.88),(10,0.825),(12,0.795),(14,0.785)
,(16,0.755),(18,0.74),(20,0.72))

F eff OT fatigue wo comp ([(0,0.68)-(20,1)],(0,1),(1.053,0.98)
,(2.105,0.955),(3.158,0.945),(4.211,0.93),(5.263,0.915),(6.316,0.905)
,(7.368,0.865),(8.421,0.845),(9.474,0.82),(10.53,0.79),(11.58,0.785)
,(12.63,0.775),(13.68,0.76),(14.74,0.755),(15.79,0.735),(16.84,0.72)
,(17.89,0.705),(18.95,0.695),(20,0.68))

F EFFBdwnNRCInv P2 2 ([(0,1)-(1,3)],(0,1),(0.1,1),(0.2,1.006)
,(0.3,1.045),(0.4,1.31),(0.5,1.735),(0.6,2.069),(0.7,2.483),
(0.8,2.713),(0.9,2.862),(1,2.977))

F EFFPucROE ([(0,-1)-(1,1.39)],(0,-0.808),(0.1,-0.268),(0.2,0.008)
,(0.3,0.308),(0.4,0.572),(0.5,0.812),(0.6,0.992),(0.7,1.04),
(0.8,1.232),(0.9,1.328),(1,1.388))

F EFFPUCStRisk ([(0,0.997)-(1,1.3)],(0,1.297),(0.1,1.261),
(0.2,1.201),(0.3,1.159),(0.4,1.114),(0.5,1.075),(0.6,1.036),
(0.7,1.006),(0.8,0.997),(0.9,1),(1,1))

F EFF DEFRED repeat reps ([(0.6,1)-(1,1.5)],(0.6,1.495),(0.64,1.478)
,(0.68,1.465),(0.72,1.438),(0.76,1.375),(0.8,1.21),(0.84,1.128)
,(0.88,1.06),(0.92,1.018),(0.96,1),(1,1))

F EFF Estaff exp ([(0.6,0.75)-(1,1.1)],(0.6,0.75),(0.65,0.773)
,(0.7,0.804),(0.75,0.853),(0.8,0.897),(0.85,0.953),(0.9,1),(0.95,1.055)
,(1,1.1))

F eff info wld OT ([(0,0)-(4,4)],(0,0),(0.333,0.14),(0.667,0.42)
,(1,0.84),(1.333,1.16),(1.667,1.42),(2,1.7),(2.333,2.04),(2.667,2.34)
,(3,2.8),(3.333,3.2),(3.667,3.62),(4,4))

F Plant demand ([(0,0)-(520,200)],(0,100),(24.8,100),(49.5,100)
,(74.3,100),(99,100),(124,100),(149,100),(173,100),(198,100)
,(223,100),(248,100),(272,100),(297,100),(322,100),(347,100)
,(371,100),(396,100),(421,100),(446,100),(470,100),(495,100)
,(520,100))

F eff mgr mnt wld OT ([(0,0)-(4,4)],(0,0),(0.333,0.12),(0.667,0.36)
,(1,0.66),(1.333,0.98),(1.667,1.22),(2,1.62),(2.333,1.92),(2.667,2.16)
,(3,2.56),(3.333,2.98),(3.667,3.34),(4,4))

F eff motivation mgr WO comp ([(1,1)-(4,1.15)],(1,1.148),(1.25,1.089)
,(1.5,1.067),(1.75,1.051),(2,1.037),(2.25,1.029),(2.5,1.024)
,(2.75,1.02),(3,1.016),(3.25,1.013),(3.5,1.008),(3.75,1.004)
,(4,1.002))

F eff motivation WO comp ([(0,0)-(12,2)],(0,1),(1,1),(2,1)
,(3,1),(4,1),(5,1),(6,1),(7,1),(8,1),(9,1),(10,1),(11,1),(12,1))

F Eff Ops ([(0,0)-(100,10)],(0,4.925),(10,3.375),(20,2.225)
,(30,1.225),(40,0.725),(50,0.475),(60,0.25),(70,0.15),(80,0.1)
,(90,0.075),(100,0.025))

F Eff ot DG ([(0,1)-(20,1.5)],(0,1),(2,1),(4,1),(6,1.05),(8,1.1)
,(10,1.15),(12,1.2),(14,1.25),(16,1.3),(18,1.35),(20,1.5))

F eff OT fatigue eng ([(0,0.8)-(20,1)],(0,1),(2.22,0.982),(4.44,0.956)
,(6.67,0.917),(8.89,0.87),(11.1,0.844),(13.3,0.827),(15.6,0.814)
,(17.8,0.804),(20,0.802))

F EFFBdwnNRCInv ([(0,0.937)-(1,1.3)],(0,0.937),(0.1,0.997)
,(0.2,1.006),(0.3,1.018),(0.4,1.039),(0.5,1.117),(0.6,1.186)
,(0.7,1.243),(0.8,1.279),(0.9,1.291),(1,1.3))

F EFFBdwnNRCInv P2 ([(0,1)-(1,1.3)],(0,1),(0.1,1),(0.2,1.006)
,(0.3,1.018),(0.4,1.048),(0.5,1.117),(0.6,1.186),(0.7,1.243)
,(0.8,1.279),(0.9,1.291),(1,1.3))

F eff plan wld OT ([(0,0)-(4,4)],(0,0),(0.333,0.14),(0.667,0.36)
,(1,0.66),(1.333,0.86),(1.667,1.14),(2,1.36),(2.333,1.74),(2.667,2.14)
,(3,2.44),(3.333,2.8),(3.667,3.12),(4,4))

F eff prod pres on Mgt OT ([(1,1)-(1.5,2)],(1,1.025),(1.042,1.175)
,(1.083,1.315),(1.125,1.425),(1.167,1.525),(1.208,1.625),(1.25,1.7)
,(1.292,1.775),(1.333,1.835),(1.375,1.89),(1.417,1.93),(1.458,1.97)
,(1.5,2))

F eff prod pres on E OT ([(1,1)-(1.5,2)],(1,1.025),(1.042,1.175)
,(1.083,1.315),(1.125,1.425),(1.167,1.525),(1.208,1.625),(1.25,1.7)
,(1.292,1.775),(1.333,1.835),(1.375,1.89),(1.417,1.93),(1.458,1.97)
,(1.5,2))

F EFF reg aband tot eng man ([(0,0)-(1,1)],(0,1),(0.1,0.875)
,(0.2,0.725),(0.3,0.405),(0.4,0.24),(0.5,0.1),(0.6,0.025),(0.7,0.015)
,(0.8,0.005),(0.9,0),(1,0.005))

F EFF regrev ([(0,1)-(1,3.5)],(0,3.5),(0.1,3.325),(0.2,3.1)
,(0.3,2.788),(0.4,2.313),(0.5,1.888),(0.6,1.525),(0.7,1.313)
,(0.8,1.175),(0.9,1.088),(1,1))

F EFF rep analysis ratio SALP ([(0,0.8)-(1,2.5)],(0,2.492)
,(0.1,2.441),(0.2,2.254),(0.3,2.015),(0.4,1.506),(0.5,1.234)
,(0.6,1.14),(0.7,1.076),(0.8,1),(0.9,0.93),(1,0.807))

F EFF SALP info ([(1,0)-(4,0.25)],(1,0),(1.5,0),(2,0),(2.5,0)
,(2.999,0),(3,0.05),(3.4999,0.05),(3.5,0.1),(4,0.1))

F eff schd planning on maint hrs ([(0,0)-(1,10)],(0,1),(0.25,1.38)
,(0.5,1.76),(0.75,2.14),(1,2.52))

F eff wload mgr work wo comp ([(0,0.75)-(1,1)],(0,0.752),(0.125,0.766)
,(0.25,0.814),(0.375,0.852),(0.5,0.883),(0.625,0.916),(0.75,0.944)
,(0.875,0.975),(1,1))

F eff wload OT ([(0,0)-(4,4)],(0,0),(0.4,0.28),(0.8,0.42),
(1.2,0.52),(1.6,0.72),(2,1.08),(2.4,1.36),(2.8,1.82),(3.2,2.46)
,(3.6,3.3),(4,4))

F EFFEBCM ([(0,0.5)-(100,10)],(0,0.595),(10,0.643),(20,0.595)
,(30,0.595),(40,0.643),(50,0.833),(60,1.165),(70,1.403),(80,2.495)
,(90,4.775),(100,9.715))

F EFFBdwnLM ([(0,0.7)-(1,1.3)],(0,0.982),(0.1,1),(0.2,1),(0.3,1)
,(0.4,1),(0.5,1.009),(0.6,1.039),(0.7,1.066),(0.8,1.102),(0.9,1.126)
,(1,1.153))

F EFFBdwnLM P2 ([(0,0.7)-(1,1.3)],(0,0.946),(0.1,1),(0.2,1)
,(0.3,1),(0.4,1),(0.5,1.009),(0.6,1.039),(0.7,1.099),(0.8,1.213)
,(0.9,1.264),(1,1.294))

F EFFBdwnNRCIn ([(0,0)-(1,0.5)],(0,0),(0.1,0),(0.2,0),(0.3,0.005)
,(0.4,0.018),(0.5,0.078),(0.6,0.165),(0.7,0.308),(0.8,0.45),
(0.9,0.493),(1,0.5))

F EFFBdwnNRCIn 2 ([(0,0)-(1,0.5)],(0,0),(0.1,0),(0.2,0),(0.3.0.005)
,(0.4,0.018),(0.5,0.078),(0.6,0.165),(0.7,0.308),(0.8,0.45),
(0.9,0.493),(1,0.5))

F EFFTDCM ([(0,0.96)-(5,3)],(0,0.96),(0.5,1.001),(1,1.063)
,(1.5,1.094),(2,1.145),(2.5,1.237),(3,1.401),(3.5,1.668),(4,1.924)
,(4.5,2.18),(5,2.969))

F Engineering ([(0,0)-(4,4)],(0.2,1),(0.579999,1),(0.58,2)
,(0.96,2),(1.34,2),(1.71999,2),(1.72,2),(2.1,2),(2.1,3),(2.48,3)
,(2.85999,3),(2.86,4),(3,4),(3.24,4),(3.62,4),(4,4))

F Frac max alloc ([(0,0)-(10,1)],(0,0.114),(10,1))

F frac of press releases print as op reps ([(0,0)-(2,1)],(0,0.038)
,(0.2,0.038),(0.4,0.065),(0.6,0.09),(0.8,0.15),(1,0.21),(1.2,0.295)
,(1.4,0.365),(1.6,0.485),(1.8,0.69),(2,0.995))

F EFFCaprel frcst ([(0,0.97)-(1.5,1.03)],(0,0.971),(0.15,0.978)
,(0.3,0.986),(0.45,0.993),(0.6,1.001),(0.75,1.007),(0.9,1.011)
,(1.05,1.015),(1.2,1.018),(1.35,1.023),(1.5,1.03))

F Maintenance ([(0,0)-(1,4)],(0,4),(0.1,4),(0.1999,4),(0.2,3)
,(0.3,3),(0.4,3),(0.4999,3),(0.5,2),(0.6,2),(0.7,2),(0.8,2),
(0.8999,2),(0.9,1),(1,1))

F Morale ([(0,0)-(520,2)],(0,1),(52,1),(104,1),(156,1),(208,1)
,(260,1),(312,1),(364,1),(416,1),(468,1),(520,1))

F EFFCLPI ([(0,0)-(250,2)],(0,1),(25,1.02),(50,1.05),(75,1.075)
,(100,1.1),(125,1.125),(150,1.15),(175,1.175),(200,1.2),(225,1.225)
,(250,1.25))

F EFFCPRCS ([(0,0)-(5,1.2)],(0,1.074),(0.5,1.038),(1,1),(1.5,0.756)
,(2,0.552),(2.5,0.426),(3,0.342),(3.5,0.222),(4,0.108),(4.5,0.036)
,(5,0))

F eff maint wld OT ([(0,0)-(4,4)],(0,0),(0.333,0.18),(0.667,0.4)
,(1,0.72),(1.333,1.02),(1.667,1.34),(2,1.7),(2.333,2.18),(2.667,2.44)
,(3,2.76),(3.333,3.12),(3.667,3.6),(4,4))

F EFFFOCM ([(0,0.9)-(5,1.4)],(0,0.9),(0.5,0.943),(1,1.01),
(1.5,1.06),(2,1.11),(2.5,1.188),(3,1.238),(3.5,1.293),(4,1.333)
,(4.5,1.36),(5,1.4))

F Service Level ([(0,0)-(1.332,1)],(0,0),(0.111,0.06),(0.222,0.195)
,(0.333,0.6),(0.444,0.805),(0.555,0.88),(0.666,0.91),(0.777,0.935)
,(0.888,0.965),(0.999,0.985),(1.11,0.99),(1.221,0.99),(1.332,0.99)
,(1.55,0.99),(1.67,0.99),(1.78,0.99),(1.89,0.99),(2,0.99),(2.11,0.99)
,(2.22,0.99))

F Support ([(0,1)-(2,4)],(0,1),(0.19999,1),(0.19999,2),(0.2,2)
,(0.3999,2),(0.4,2),(0.59999,2),(0.6,3),(0.8,3),(1,3),(1.2,3)
,(1.39999,3),(1.4,4),(1.6,4),(1.8,4),(2,4))

F unschd eff plan pct hr wtime ([(0,1)-(1,1.68)],(0,1),(0.25,1.17)
,(0.5,1.34),(0.75,1.51),(1,1.68))

F EFFMLM ([(0,0.7)-(10,1.3)],(0,0.823),(1,0.997),(2,1),(3,1)
,(4,1.006),(5,1.021),(6,1.057),(7,1.114),(8,1.222),(9,1.282)
,(10,1.297))

F eff wload pln prod ([(0,0)-(0.4,1)],(0,0),(0.05,0.455),(0.1,0.705)
,(0.15,0.85),(0.2,0.92),(0.25,0.955),(0.3,0.97),(0.35,0.985)
,(0.4,1))

F Eff Breakdwn P2 ([(0,0)-(1,5)],(0,0),(0.1,0.025),(0.2,0.15)
,(0.3,0.825),(0.4,1.65),(0.5,2.5),(0.6,3.325),(0.7,3.975),(0.8,4.475)
,(0.9,4.875),(1,4.975))

F Eff Breakdwn ([(0,0)-(1,10)],(0,0),(0.1,0.025),(0.2,0.05)
,(0.3,0.2),(0.4,0.5),(0.5,1.12),(0.6,2.42),(0.7,3.9),(0.8,4.47)
,(0.9,4.88),(1,4.97))

F EFFPIPO ([(0,0.9)-(3,1.1)],(0,0.981),(0.3,0.981),(0.6,0.983)
,(0.9,0.992),(1.2,1.001),(1.5,1.014),(1.8,1.025),(2.1,1.042)
,(2.4,1.056),(2.7,1.059),(3,1.069))

F EffPUCRB ([(0,-0.2)-(1,0.1)],(0,-0.194),(0.034,-0.126),(0.069,-0.084)
,(0.103,-0.018),(0.172,-0.01),(0.207,-0.008),(0.241,-0.004),
(0.276,0),(0.31,0),(0.345,0),(0.379,0),(0.414,0),(0.448,0),(0.483,0)
,(0.552,0),(0.586,0),(0.621,0),(0.655,0),(0.724,0),(0.759,0)
,(0.793,0),(0.828,0),(0.862,0),(0.897,0),(0.931,0.006),(0.966,0.016)
,(1,0.056),(517,0))

F Eff Mgt staff exp ([(0.7,0.7)-(1,1.2)],(0.7,0.7),(0.73,0.835)
,(0.76,0.873),(0.79,0.89),(0.82,0.905),(0.85,0.925),(0.88,0.958)
,(0.91,1.003),(0.94,1.065),(0.97,1.138),(1,1.2))

F eff wload wo comp ([(0,0)-(1,1)],(0,0),(0.125,0.025),(0.25,0.09)
,(0.375,0.17),(0.5,0.32),(0.625,0.435),(0.75,0.595),(0.875,0.83)
,(1,1))

F EFFSALPlocpub opp ([(1,0)-(4,2)],(1,1),(1.33,1),(1.67,1)
,(2,1),(2.33,1),(2.67,1),(3,1),(3.33,1),(3.67,1),(4,1))

F EFFSALPnat pub opp ([(1,0)-(4,20)],(1,1),(1.333,1),(1.667,1)
,(2,1),(2.333,1),(2.667,1),(3,1),(3.333,1),(3.667,1),(4,11))

F EFFsitclandemerg NRCIns ([(0,0)-(5,0.2)],(1,0),(1.4,0),(1.8,0)
,(2.2,0.002),(2.6,0.017),(3,0.034),(3.4,0.048),(3.8,0.072),(4.2,0.105)
,(4.6,0.148),(5,0.198))

F Plant breakdwns P2 ([(0,0)-(1,10)],(0,0),(0.1,0.1),(0.2,0.2)
,(0.3,0.65),(0.4,1.25),(0.5,4),(0.6,6.65),(0.7,7.95),(0.8,8.9)
,(0.9,9.65),(1,9.9))

F frac w plans ([(0,0)-(1,0.935)],(0,0),(0.1,0.18),(0.2,0.345)
,(0.3,0.47),(0.4,0.585),(0.5,0.66),(0.6,0.715),(0.7,0.78),(0.8,0.83)
,(0.9,0.885),(1,0.935))

F New Staff Hiring ([(0,-0.6)-(10,2)],(0,-0.5),(1,-0.14),(2,0.05)
,(3,0.1),(4,0.2),(5,0.35),(6,0.463),(7,0.613),(8,0.913),(9,1.4)
,(10,2))

F eff mgr info wld OT ([(0,0)-(4,4)],(0,0),(0.333,0.16),(0.667,0.48)
,(1,0.72),(1.333,0.98),(1.667,1.32),(2,1.68),(2.333,2.06),(2.667,2.4)
,(3,2.7),(3.333,3.14),(3.667,3.4),(4,4))

F Spec upgrade per part ([(0,0)-(100,10)],(0,0.016),(10,0.048)
,(20,0.064),(30,0.16),(40,0.392),(50,0.632),(60,0.976),(70,1.24)
,(80,1.376),(90,1.472),(100,1.516))

F eff motivation eng WO comp ([(1,1)-(4,1.15)],(1,1.148),(1.25,1.089)
,(1.5,1.067),(1.75,1.051),(2,1.037),(2.25,1.029),(2.5,1.024)
,(2.75,1.02),(3,1.016),(3.25,1.013),(3.5,1.008),(3.75,1.004)
,(4,1.002))

F eff wload eng wo comp ([(0,0.751)-(1,1)],(0,0.751),(0.125,0.768)
,(0.25,0.8),(0.375,0.862),(0.5,0.906),(0.625,0.938),(0.75,0.96)
,(0.875,0.977),(1,1))

F EFF main OT info ([(0,0.75)-(20,1)],(0,0.998),(2,0.994),
(4,0.983),(6,0.963),(8,0.944),(10,0.914),(12,0.868),(14,0.829)
,(16,0.799),(18,0.77),(20,0.751))

F Operating Conditions ([(0,0)-(100,2.78)],(0,2.775),(10,2.725)
,(20,2.525),(30,1.625),(40,0.775),(50,0.475),(60,0.275),(70,0.175)
,(80,0.1),(90,0),(100,0))

F capacity tdwn ([(0,0)-(1,1)],(0,0),(0.1,0.04),(0.2,0.095)
,(0.3,0.17),(0.4,0.26),(0.5,0.4),(0.6,0.585),(0.7,0.725),(0.8,0.845)
,(0.9,0.945),(1,1))

F EFFBEOL ([(0,0.95)-(1,1.1)],(0,0.951),(0.1,0.967),(0.2,0.979)
,(0.3,0.991),(0.4,1.006),(0.5,1.028),(0.6,1.045),(0.7,1.054)
,(0.8,1.068),(0.9,1.081),(1,1.099))

F EFFDefldbrkdn ([(0,0)-(0.2,10)],(0,0.01),(0.02,0.11),(0.04,0.185)
,(0.06,0.275),(0.08,0.4),(0.1,0.52),(0.12,0.63),(0.14,0.74),
(0.16,0.83),(0.18,0.925),(0.2,1))

F frac equip pff dfct ([(0,0)-(2,1)],(0,0),(0.2,0.134),(0.4,0.268)
,(0.6,0.39),(0.8,0.5),(1,0.595),(1.2,0.7),(1.4,0.8),(1.6,0.885)
,(1.8,0.955),(2,1))

F frac equip pm dfct ([(0,0)-(2,1)],(0,0),(0.2,0.134),(0.4,0.268)
,(0.6,0.39),(0.8,0.5),(1,0.595),(1.2,0.7),(1.4,0.8),(1.6,0.885)
,(1.8,0.955),(2,1))

Appendix C: Sensitivity Analysis Results

C-1. Simulation Results

C-2. Assumptions

C-3. Graph Presentations

C-1. Simulation Results

A. Nuclear Power Plant Sector

No	Variable	Initial Transient	Steady State
1	DR equip per wo	Change	Behavior mode
2	DR customer demand	Change	Behavior mode
3	DR frac dfct bdwn	Change	Behavior mode
4	DR base dfcts ops per week	Change	Behavior mode
5	DR base dfcts f wmanship	Change	Numerical
6	DR base dfcts per bdwn	Change	Numerical
7	DR base frac mat dfct at delvry	Change	Numerical
8	D mechanic experience cost factor	Change	Behavior mode
9	D target frac plan	Change	Numerical
10	DR mat acq delay	Change	Behavior mode
11	D schd WO memory	Change	Numerical
12	D time to tdwn	Change	Numerical
13	D schd WO per mod CA	Change	Numerical
14	D eng and mgr forget time	No Change	No Change
15	DR unschd backlog time	Change	Behavior mode
16	D utilization	Change	Numerical
17	DR attrition	No Change	No Change
18	D bud layoff time	No Change	No Change
19	D contractor hiring	No Change	No Change
20	D layoff fraction	No Change	Behavior mode
21	D maint hiring delay	No Change	No Change
22	DR standard hours	Change	Numerical
23	D target frac OT	Change	Numerical
24	D target weeks work	Change	Behavior mode
25	D time to change ave OT	No Change	No Change
26	DR base frac schd WO hrs maint hrs	Change	No Change
27	DR base frac unschd WO hrs maint hrs	Change	Numerical
28	DR maint hrs per schd WO	Change	No Change
29	DR maint hrs per unschd WO	Change	Numerical
30	DR base pln prod W plan	Change	Numerical
31	DR base pln prod WT plan	Change	Numerical
32	D max plans	Change	No Change
33	DR obsolesence time	No Change	No Change
34	DR planners per WO req mat	Change	Behavior mode
35	DR ave time between dinsp	Change	No Change
36	DR ave time between minsp	Change	Numerical
37	DR ave time for dinsp	Change	Numerical
38	DR ave time for minsp	Change	Numerical
39	DR frac dinsp req tdwn	Change	No Change
40	DR frac equip insp	Change	No Change
41	DR frac minsp req tdwn	Change	No Change
42	DR prob fa lawsuite pos	No Change	No Change
43	DR prob miss dfct dinsp	Change	Numerical

44	DR prob miss dfct minsp	No Change	No Change
45	D aging time	Change	No Change
46	D buy time	No Change	No Change
47	DR cost new cap part	No Change	No Change
48	DR cost per part des	No Change	No Change
49	DR dollar per new eq	No Change	No Change
50	D init quality spec	Change	Numerical
51	DR new part des inv	No Change	No Change
52	D specs upgraded	No Change	No Change
53	DR dollars per part	Change	No Change
54	DR ave parts per WO	Change	Numerical
55	DR replacement investment	No Change	No Change
56	D target inventory as PCT ERV	No Change	No Change
57	DR eng attrition	No Change	No Change
58	D eng hiring delay	No Change	No Change
59	DR frac eng info	Change	Behavior mode
60	DR info rev per eng per week	Change	Numerical
61	D eng layoff fraction	No Change	Behavior mode
62	DR maint rev per eng per week	Change	Behavior mode
63	DR plans rev per eng per week	Change	No Change
65	D time to layoffs engs	No Change	No Change
66	D time to train engs	No Change	No Change
67	DR eng standard hours	No Change	No Change
68	D target frac eng OT	No Change	No Change
69	D time to change ave OT	No Change	No Change
70	DR cost per OT hr	No Change	No Change
71	DR attrition mgr	Change	Numerical
72	DR frac mgr fin	Change	Numerical
73	D mgr layoff fraction	No Change	Behavior mode
74	DR info rev per mgr per week	No Change	No Change
75	DR maint rev per mgr per week	Change	Behavior mode
76	D mgr hiring delay	No Change	No Change
77	D mgr time to up to speed	Change	Numerical
78	D time to layoff mgrs	No Change	Numerical
80	DR mgr standard hours	No Change	No Change
81	D target frac mgr OT	No Change	No Change
82	D time to change mgr OT	No Change	No Change
83	D mr per insp	No Change	No Change
84	D mr percent	No Change	No Change
85	D mr per FO	No Change	No Change
86	D mr per unschd WO	No Change	No Change
87	D mr per schd WO	No Change	No Change

B. Social Sector

No	Variable	Initial Transient	Steady State
88	D ave desensitzation[NA]	No Change	No Change
89	D ave desensitzation[LO]	No Change	No Change
90	DR dollar on education	No Change	No Change
91	D ave rpt effect life	No Change	No Change
92	D evt rpt spread time	No Change	No Change
93	D fwup rpt spread time	No Change	No Change
94	D op rpt spread time	No Change	No Change
95	DR ave time to dismiss	No Change	No Change
96	DR ave time to settle	No Change	No Change
97	DR ave trial duration	No Change	No Change
98	D ave campaign effect life	No Change	No Change
99	D ave campaign development time	No Change	No Change
100	D frac campaign failed	No Change	No Change

C. Government Sector

No	Variable	Initial Transient	Steady State
101	DR base insp rate	No Change	No Change
102	DR time to insp	No Change	No Change
103	DR ave no reports per res proj	Change	Behavior mode
104	DR ave res proj duration	Change	Numerical
105	DR ave time to publish report	Change	Numerical
106	D response time	No Change	No Change
107	DR ave life of unsucessful reg efforts	Change	Numerical
108	DR ave regulations sought per report	Change	Behavior mode
109	DR time to enact regulation	Change	Numerical
110	DR Discarding regulations	Change	No Change
111	DR lawmakers	No Change	No Change
112	D ave lmkr memory	No Change	No Change

D. Information Sector

No	Variable	Initial Transient	Steady State
113	D event per year	No Change	No Change
114	D prob disc per alert	Change	Numerical
115	D prob disc per emergency	No Change	No Change
116	D prob disc per unusual event	Change	Numerical
117	D time horizon to comp ind probs	No Change	No Change
118	DR base prob sa	No Change	No Change
119	DR base prob se	No Change	No Change
120	DR base EPRI res	No Change	No Change
121	DR base VEN res	No Change	No Change
122	DR base WANO rep	No Change	Numerical
123	D frac probs need in	No Change	Numerical
124	D time to completion[VEN]	No Change	No Change
125	D time to completion[NRC]	No Change	No Change
126	D time to completion[EPR]	No Change	No Change
127	D time to completion[WAN]	No Change	No Change
128	DR frac probs sent to INPO	Change	Numerical
129	DR frac probs sent to NRC	No Change	No Change
130	DR frac probs sent to vendors	No Change	No Change
131	DR frac sig probs	Change	Numerical
132	DR INPO time to analyze probs	No Change	No Change
133	DR INPO time to screen event	No Change	No Change
134	DR frac recs req quick SOER	Change	Numerical
135	DR frac sig probs req recs	Change	Numerical
136	DR INPO time to comp FI	No Change	No Change
137	DR INPO time to plan FI	No Change	No Change
138	DR INPO time to produce quick SOER	No Change	Numerical
139	DR eng needed per FI	No Change	No Change
140	DR frac prob req SEN	No Change	Numerical
141	DR INPO eng needed per action	No Change	No Change
142	DR max INPO eng available	No Change	No Change
143	DR time to produce SER	No Change	No Change
144	DR concerns per SOER	Change	Numerical
145	DR frac rep abandoned	No Change	No Change
146	DR frac reps prev analyzed	Change	Numerical
147	DR frac SOER dtmd app	Change	Numerical
148	DR time to screen reps	No Change	Numerical
149	DR time to screen SOER	No Change	No Change
150	D frac of probs regeval	Change	Numerical
151	DR frac prob need quick CA	No Change	No Change
152	DR frac probs screen by NWE	No Change	No Change
153	DR probs per defect	Change	Numerical
154	DR time to screen probs	No Change	Numerical
155	D eval eng unavail lim	No Change	No Change
156	D frac eva lawsuit abandoned	No Change	No Change

157	DR time to eval	Change	Numerical
158	DR time to val eva lawsuit	Change	Numerical
159	D assign eng unavail lim	No Change	No Change
160	D assign mgr unavail lim	Change	Numerical
161	D frac CA abandon	No Change	No Change
162	D frac eva lawsuit need mult CA	Change	Numerical
163	DR frac of eva lawsuit need CA	Change	Numerical
164	DR time to assign CA	Change	Numerical
165	DR frac CA mod	Change	Numerical
166	DR frac CA proc	Change	Numerical
167	DR frac CA train	Change	Numerical
168	DR time to comp proc CA	Change	Numerical
169	DR time to comp train CA	Change	Numerical
170	DR time to plan mod CA	Change	Numerical
171	DR time to val proc CA	Change	Numerical
172	DR time to val train CA	No Change	Numerical
173	DR frac of regs to review	No Change	No Change
174	DR frac regs des aband	Change	Numerical
175	DR time to assign reg review	No Change	No Change
176	DR time to comp reg rev	No Change	No Change
177	DR CA per reg	No Change	No Change
178	DR frac regs abandoned	No Change	No Change
179	DR time to comp reg eval	No Change	No Change
180	DR time to influence NRC	No Change	No Change
181	DR info eng WTB per reg	No Change	No Change
182	DR managers applied per job	Change	Numerical
183	DR mgr WTB per reg	No Change	No Change
184	DR LC frac info	Change	Behavior mode
185	DR defects per press release	No Change	No Change
186	DR SALP reporting per year	No Change	No Change

E. Financial Resources Sector

No	Variable	Initial Transient	Steady State
187	DR decom costs	No Change	No Change
188	DR dividend factor	No Change	No Change
189	DR discount rate	No Change	No Change
190	DR bught pow rat	No Change	No Change
191	DR cost per LAWSUIT	No Change	No Change
192	DR HL waste mgt	Change	Behavior mode
193	DR ops overhead	Change	Behavior mode
194	DR unit $ fuel	Change	Behavior mode
195	DR cost per insp	No Change	No Change
196	DR eng annual salary	No Change	No Change
197	DR hrly cost labor	Change	Behavior mode
198	D overhead eff	Change	No Change
199	DR annual fixed costs	Change	Behavior mode
200	D evil amount	No Change	No Change
201	D for cap	No Change	No Change
202	D Rate base decision delay	No Change	No Change
203	D system reliability	No Change	No Change
204	DR power rating	Change	Numerical
205	DR frac bud eng	No Change	No Change
206	DR frac bud lobby	No Change	No Change
207	DR frac bud mech	No Change	No Change
208	DR frac bud mgr	No Change	No Change
209	DR frac bud parts	Change	Numerical
210	DR frac bud training	Change	Behavior mode
211	DR frac part bud maint parts	Change	Numerical
212	DR mgr annual salary	Change	Behavior mode
213	D desired return on equity	Change	Behavior mode
214	DR frac div	No Change	No Change
215	D desired DE ratio	No Change	No Change
216	DR stock mkt SS	No Change	No Change
217	D T bill rate	No Change	No Change
218	D equity factor	No Change	No Change
219	DR time to sell shares	No Change	No Change
220	D speculation factor	No Change	No Change
221	D debt factor	No Change	No Change

C-2. Assumptions

A. Nuclear Power Plant Sector

No	Variable	Base case	Assumptions	Unit
1	DR equip per wo	4	3, 5	equipment/work order
2	DR customer demand	80	70, 90, 95	percentage
3	DR frac dfct bdwn	1/12	6, 9, 15, 18	breakdowns/defects/week
4	DR base dfcts ops per week	0.115*(1-frac new equip)	0.1, 0.12, 0.15	defects/equipment/week
5	DR base dfcts f wmanship	0.35	0.3, 0.4	defects/equipment
6	DR base dfcts per bdwn	0.45	0.4, 0.5	defects/breakdown
7	DR base frac mat dfct at delvry	0.25	0.2, 0.3	
8	D mechanic experience cost factor	1.05	0.5, 1.5, 2.0	
9	D target frac plan	0.5	0.4, 0.7	
10	DR mat acq delay	0.5	1.0, 1.5	weeks
11	D schd WO memory	26	13, 39, 52	weeks
12	D time to tdwn	0.5	1.0, 1.5	weeks
13	D schd WO per mod CA	4	3, 5	work orders/corrective action
14	D eng and mgr forget time	12	8, 16	weeks
15	DR unschd backlog time	1	0.5, 1.5, 2.0	weeks
16	D utilization	0.7	0.5, 0.9	
17	DR attrition	0.05*Maintenance Staff	0.04, 0.07	mechanics/week
18	D bud layoff time	6	3, 5, 8	weeks
19	D contractor hiring	150	100, 300, 500	persons
20	D layoff fraction	0 at 100 week	0.1, 0.2, 0.3	
21	D maint hiring delay	8	5, 7, 12	weeks
22	DR standard hours	40	36, 48	hours/person/week
23	D target frac OT	0.1	0.05, 0.125, 0.2	
24	D target weeks work	2	1, 3, 4	weeks
25	D time to change ave OT	1	0.5, 2	weeks
26	DR base frac schd WO hrs maint hrs	0.27	0.25, 0.30, 0.35	
27	DR base frac unschd WO hrs maint hrs	0.25	0.225, 0.27	
28	DR maint hrs per schd WO	1.8	1.5, 2.0	hours/work order
29	DR maint hrs per unschd WO	1.8	1.5, 2.0	hours/work order
30	DR base pln prod W plan	30	25, 35, 40	plans/planner/week
31	DR base pln prod WT plan	8	4, 10, 12	plans/planner/week
32	D max plans	26,000*5	4, 6, 8	plans
33	DR obsolesence time	10*52	5, 8, 12	weeks
34	DR planners per WO req mat	2.5/40	1.5, 5.0, 7.5	people/work order
35	DR ave time between dinsp	20	15, 25, 30	weeks
36	DR ave time between minsp	25.5/EFF NRC MINSP	20, 22.5, 30	weeks
37	DR ave time for dinsp	5/equip per WO	4, 8, 10	hours/inspection
38	DR ave time for minsp	10/equip per WO	5, 12, 15	hours/inspection
39	DR frac dinsp req tdwn	0.15	0.1, 0.2, 0.3	
40	DR frac equip insp	0.6	0.3, 0.5, 0.9	
41	DR frac minsp req tdwn	0.3	0.1, 0.2, 0.5	

42	DR prob fa lawsuite pos	0.05	0.03, 0.08, 0.1	
43	DR prob miss dfct dinsp	0.15	0.1, 0.3, 0.5	
44	DR prob miss dfct minsp	0.03	0.1, 0.05, 0.1	
45	D aging time	26	13, 39, 52	weeks
46	D buy time	2	1, 1.5, 4	weeks
47	DR cost new cap part	2.5	2, 4, 5	million $/part
48	DR cost per part des	0.025	0.02, 0.03, 0.05	million $/part
49	DR dollar per new eq	0.1	0.05, 0.2, 0.3	million $/equipment
50	D init quality spec	60	30, 70, 90	
51	DR new part des inv	1.5*5	3, 4, 8	million $
52	D specs upgraded	rejects*0.2	0.1, 0.3, 0.5	
53	DR dollars per part	4.2/52*374*ave part per WO	4, 4.5, 5	million $/part
54	DR ave parts per WO	5	3, 4, 5.5	parts/work order
55	DR replacement investment	444	400, 500, 600	million $
56	D target inventory as PCT ERV	1.09	0.95, 1.15, 1.3	
57	DR eng attrition	.001*Pro Engineers	0.0005, 0.002	engineers/week
58	D eng hiring delay	4	2, 6, 8	weeks
59	DR frac eng info	0.3	0.1, 0.2, 0.4	
60	DR info rev per eng per week	16	8, 20, 24	reviews/engineer/week
61	D eng layoff fraction	0 at 100 week	0.1, 0.2, 0.3	
62	DR maint rev per eng per week	8	4, 6,12	reviews/engineer/week
63	DR plans rev per eng per week	16	8, 20, 24	reviews/engineer/week
65	D time to layoffs engs	12	8, 16, 24	weeks
66	D time to train engs	26	13, 39, 52	weeks
67	DR eng standard hours	40	36, 44, 48	hours/person/week
68	D target frac eng OT	0.125	0.1, 0.2, 0.25	
69	D time to change ave OT	2	1, 4	weeks
70	DR cost per OT hr	50	25, 60, 70	million $/hour
71	DR attrition mgr	0.001*ProManagers	0.0005, 0.002	managers/week
72	DR frac mgr fin	0.2	0.1, 0.15, 0.3	
73	D mgr layoff fraction	0 at 100 week	0.1, 0.2, 0.3	
74	DR info rev per mgr per week	9	6, 12, 15	reviews/manager/week
75	DR maint rev per mgr per week	20	15, 18, 25	reviews/manager/week
76	D mgr hiring delay	4	2, 6, 8	weeks
77	D mgr time to up to speed	26	13, 39, 52	weeks
78	D time to layoff mgrs	8	4, 10, 12	weeks
80	DR mgr standard hours	40	36, 44, 48	hours/person/week
81	D target frac mgr OT	0.125	0.1, 0.2, 0.25	
82	D time to change mgr OT	2	1, 4	weeks
83	D mr per insp	0.0001	0.00005, 0.0002	
84	D mr percent	0.1	0.05, 0.15, 0.2	
85	D mr per FO	0.1	0.05, 0.15, 0.2	
86	D mr per unschd WO	0.001	0.0005, 0.002	
87	D mr per schd WO	0.0005	0.0002, 0.001, 0.002	

B. Social Sector

No	Variable	Base case	Assumptions	Unit
88	D ave desensitzation[NA]	520	260, 390, 650	weeks
89	D ave desensitzation[LO]	520	260, 390, 650	weeks
90	DR dollar on education	0.002	0.01, 0.03, 0.05	million $/week
91	D ave rpt effect life	4	2, 6, 8	weeks
92	D evt rpt spread time	2	1, 3, 4	weeks
93	D fwup rpt spread time	1.5	1, 2, 3	weeks
94	D op rpt spread time	3	1.5, 2, 5	weeks
95	DR ave time to dismiss	26	13, 39, 52	weeks
96	DR ave time to settle	2*52	1, 3, 4	weeks
97	DR ave trial duration	6*52	3, 5, 9	weeks
98	D ave campaign effect life	4	2, 6, 8	weeks
99	D ave campaign development time	12	6, 9, 18	weeks
100	D frac campaign failed	0.5	0.3, 0.4, 0.7	

C. Government Sector

No	Variable	Base case	Assumptions	Unit
101	DR base insp rate	3/52	1, 2, 5	inspection/week
102	DR time to insp	4	2, 6, 8	weeks
103	DR ave no reports per res proj	1	2, 3, 5	reports/project
104	DR ave res proj duration	1*52	0.5, 2, 3	weeks
105	DR ave time to publish report	1*52	0.5, 2, 3	weeks
106	D response time	3*4	1, 2, 5*4	weeks
107	DR ave life of unsucessful reg efforts	2*52	1, 3, 5	weeks
108	DR ave regulations sought per report	0.1	0.05, 0.2, 0.3	regulations/report
109	DR time to enact regulation	1*52	0.5, 2, 3	weeks
110	DR Discarding regulations	Regulations on Book/800	500, 600, 700	
111	DR lawmakers	535	450, 500, 600	persons
112	D ave lmkr memory	20	10, 15, 30	weeks

D. Information Sector

No	Variable	Base case	Assumptions	Unit
113	D event per year	140	120, 150, 170	event/year
114	D prob disc per alert	10	5, 15, 20	problems/alert
115	D prob disc per emergency	100	50, 150, 200	problems/emergency
116	D prob disc per unusual event	1	0.5, 1.5, 2	problems/unusual event
117	D time horizon to comp ind probs	12	9, 15, 18	weeks
118	DR base prob sa	10*TIME STEP	5, 8, 15	
119	DR base prob se	0.25*TIME STEP	0.1, 0.2, 0.5	
120	DR base EPRI res	1	0.5, 1.5, 2	programs/week
121	DR base VEN res	1	0.5, 1.5, 2	programs/week
122	DR base WANO rep	2	1, 3, 4	programs/week
123	D frac probs need in	0.5	0.25, 0.6, 0.7	
124	D time to completion[VEN]	26	13, 39, 52	weeks
125	D time to completion[NRC]	4	2, 6, 8	weeks
126	D time to completion[EPR]	12	6, 15, 18	weeks
127	D time to completion[WAN]	4	2, 6, 8	weeks
128	DR frac probs sent to INPO	1	0.5, 0.7, 0.9	
129	DR frac probs sent to NRC	1	0.5, 0.7, 0.9	
130	DR frac probs sent to vendors	0.1	0.05, 0.15, 0.3	
131	DR frac sig probs	0.8	0.4, 0.5, 0.7	
132	DR INPO time to analyze probs	2	1, 3, 4	weeks
133	DR INPO time to screen event	1	0.5, 1.5, 2	weeks
134	DR frac recs req quick SOER	0.6	0.3, 0.4, 0.8	
135	DR frac sig probs req recs	0.5	0.3, 0.4, 0.6	
136	DR INPO time to comp FI	6	3, 4, 8	weeks
137	DR INPO time to plan FI	2	1, 3, 4	weeks
138	DR INPO time to produce quick SOER	1	0.5, 1.5, 2	weeks
139	DR eng needed per FI	3	1, 2, 5	engineers
140	DR frac prob req SEN	0.2	0.1, 0.3, 0.4	
141	DR INPO eng needed per action	0.33	0.2, 0.4, 0.5	engineers/action
142	DR max INPO eng available	20	10, 40	engineers
143	DR time to produce SER	2	1, 3, 4	weeks
144	DR concerns per SOER	5	3, 4, 8	concerns/SOER
145	DR frac rep abandoned	0.4	0.2, 0.3, 0.5	
146	DR frac reps prev analyzed	0.3*EFF DEFRED REPEAT REPS	0.15, 0.5	
147	DR frac SOER dtmd app	0.8	0.5, 0.9	
148	DR time to screen reps	3	1.5, 5	weeks
149	DR time to screen SOER	1	0.5, 1.5, 2	weeks
150	D frac of probs regeval	0.75	0.5, 0.7, 0.85	
151	DR frac prob need quick CA	0.25	0.2, 0.4, 0.5	
152	DR frac probs screen by NWE	0.25*eff inc probs NWE	0.2, 0.4, 0.5	
153	DR probs per defect	1/50	2, 3, 5	problems/defect
154	DR time to screen probs	2	1, 3, 4	weeks
155	D eval eng unavail lim	3	1.5, 6	engineers

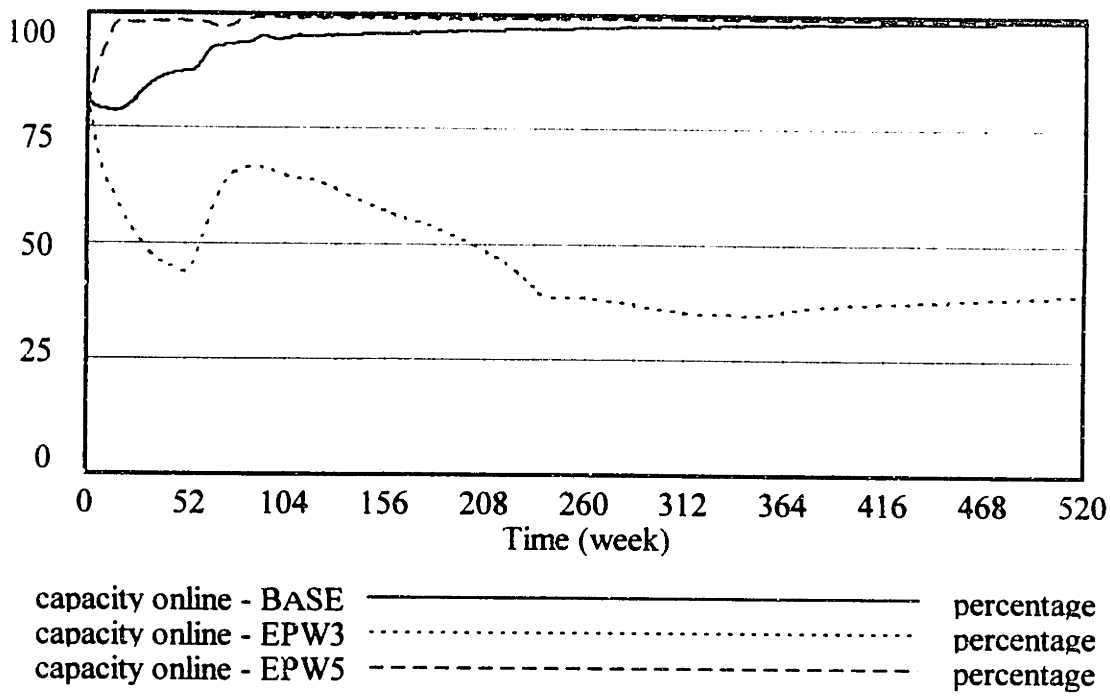
156	D frac eva lawsuit abandoned	0.1	0.05, 0.15, 0.3	
157	DR time to eval	6	3, 9, 12	weeks
158	DR time to val eva lawsuit	1	0.5, 2, 3	weeks
159	D assign eng unavail lim	3	1, 4, 6	engineers
160	D assign mgr unavail lim	2	1, 3, 5	managers
161	D frac CA abandon	0.2	0.1, 0.3, 0.5	
162	D frac eva lawsuit need mult CA	0.2	0.1, 0.3, 0.5	
163	DR frac of eva lawsuit need CA	0.75	0.5, 0.6, 0.85	
164	DR time to assign CA	1	0.5, 1.5, 2	weeks
165	DR frac CA mod	0.2	0.1, 0.3, 0.4	
166	DR frac CA proc	0.6	0.3, 0.4, 0.8	
167	DR frac CA train	0.2	0.1, 0.3, 0.4	
168	DR time to comp proc CA	10	5, 7, 15	weeks
169	DR time to comp train CA	26	13, 39, 52	weeks
170	DR time to plan mod CA	12	6, 9, 18	weeks
171	DR time to val proc CA	1	0.5, 1.5, 2	weeks
172	DR time to val train CA	2	1, 3, 4	weeks
173	DR frac of regs to review	0.9	0.7, 0.8, 0.95	
174	DR frac regs des aband	0	0.1, 0.2	
175	DR time to assign reg review	1	0.5, 1.5, 2	weeks
176	DR time to comp reg rev	12	6, 9, 18	weeks
177	DR CA per reg	253	200, 225, 275	actions/regulation
178	DR frac regs abandoned	1	0.5, 0.7, 0.8	
179	DR time to comp reg eval	6	3, 5, 9	weeks
180	DR time to influence NRC	12	6, 9, 18	weeks
181	DR info eng WTB per reg	25	15, 20, 30	engineers/regulation
182	DR managers applied per job	0.2	0.1, 0.3, 0.5	managers/job
183	DR mgr WTB per reg	10	5, 7, 15	managers/regulation
184	DR LC frac info	0.03	0.01, 0.05	
185	DR defects per press release	1000	500, 1500	defects/release
186	DR SALP reporting per year	4	2, 3	reports/year

E. Financial Resources Sector

No	Variable	Base case	Assumptions	Unit
187	DR decom costs	200	100, 150, 250	million $
188	DR dividend factor	0.75	0.5, 0.6, 0.7	
189	DR discount rate	4	3, 5, 7	%
190	DR bught pow rat	0.07	0.08, 0.09, 0.1	$/kwh
191	DR cost per LAWSUIT	1	0.5, 1.5, 2	million $
192	DR HL waste mgt	5/10E6	3,7, 10	million $/Mwe-hr
193	DR ops overhead	0.5	0.25, 0.75, 1.00	million $/week
194	DR unit $ fuel	(0.005* 1000)/10E6	0.0025, 0.0075, 0.01	million $/Mwe-hr
195	DR cost per insp	0.02	0.01, 0.03, 0.04	million $/week
196	DR eng annual salary	50,000/10E6	40000, 60000, 70000	million $/yr
197	DR hrly cost labor	30.59/10E6	25, 35, 45	million $/yr
198	D overhead eff	1.3	1.1, 1.2, 1.5	
199	DR annual fixed costs	40	20, 50, 60	million $/yr
200	D evil amount	0.055	0.045, 0.05, 0.06	
201	D for cap	0.8	0.5, 0.6, 0.7	
202	D Rate base decision delay	52	26, 39, 65	weeks
203	D system reliability	0.0995	0.99, 0.993, 0.997	
204	DR power rating	1000	1100, 1200, 1300	kwh
205	DR frac bud eng	0.175	0.15, 0.2, 0.215	
206	DR frac bud lobby	0.01	0.0075, 0.0125, 0.025	
207	DR frac bud mech	0.525	0.5, 0.55, 0.575	
208	DR frac bud mgr	0.1	0.0075, 0.125, 0.25	
209	DR frac bud parts	0.1	0.15, 0.2, 0.3	
210	DR frac bud training	0.1	0.05, 0.15, 0.2	
211	DR frac part bud maint parts	0.8	0.6, 0.7, 0.9	
212	DR mgr annual salary	100,000/10E6	75000, 125000, 150000, 175000	million $/yr
213	D desired return on equity	0.06	0.05, 0.055, 0.07	
214	DR frac div	0.75	0.5, 0.6, 0.7	
215	D desired DE ratio	1	0.95, 1.05, 1.1	
216	DR stock mkt SS	0.1	0.05, 0.07, 0.15	
217	D T bill rate	0.0535	0.05, 0.055, 0.06	
218	D equity factor	0.4	0.3, 0.35, 0.45	
219	DR time to sell shares	1	0.5, 1.5, 2	weeks
220	D speculation factor	1	0.7, 0.8, 0.9	
221	D debt factor	0.6	0.5, 0.55, 0.7	

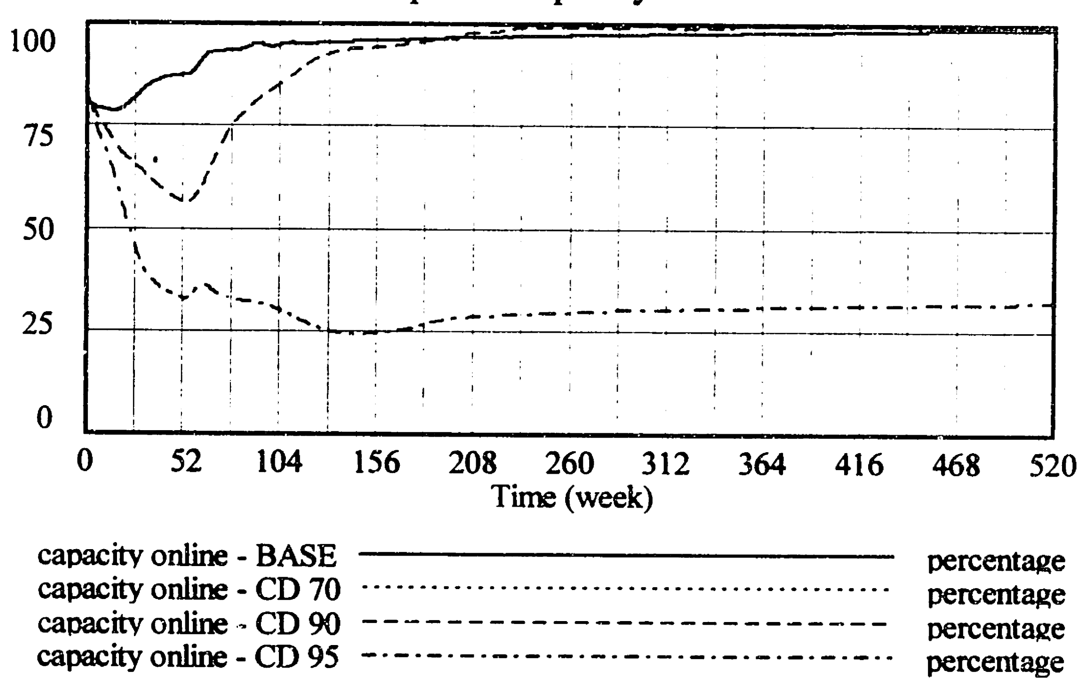
C-3. Graph Presentations

Graph for capacity online

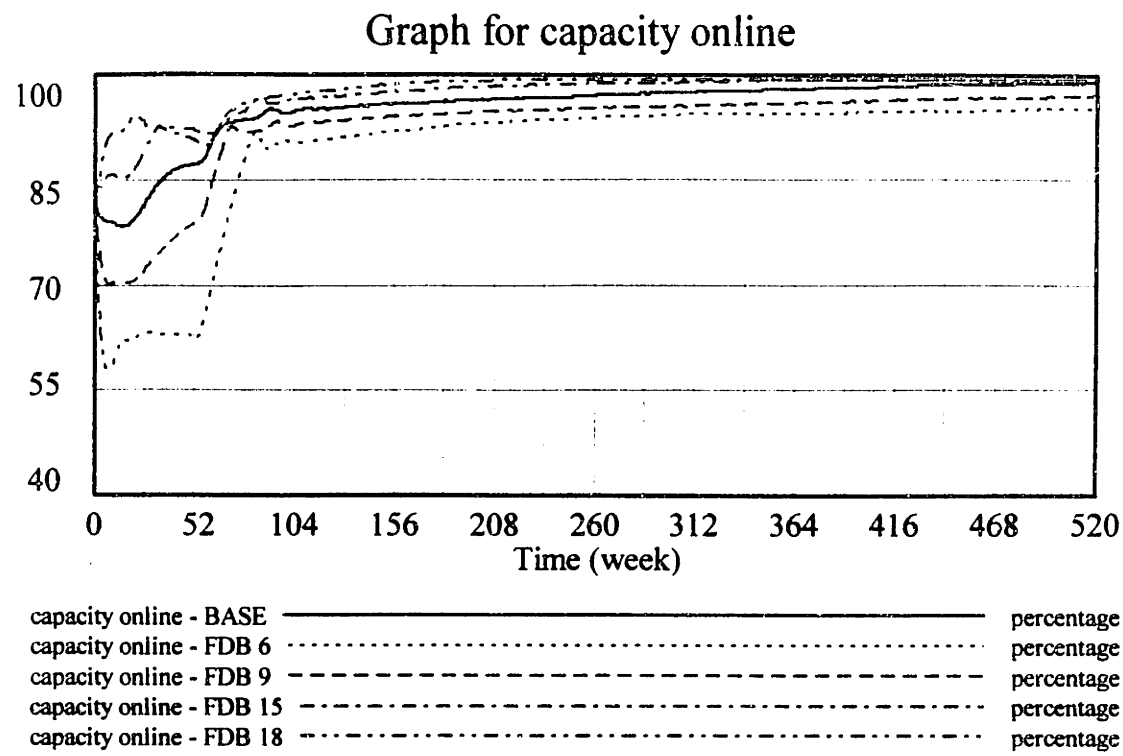


Variable 1

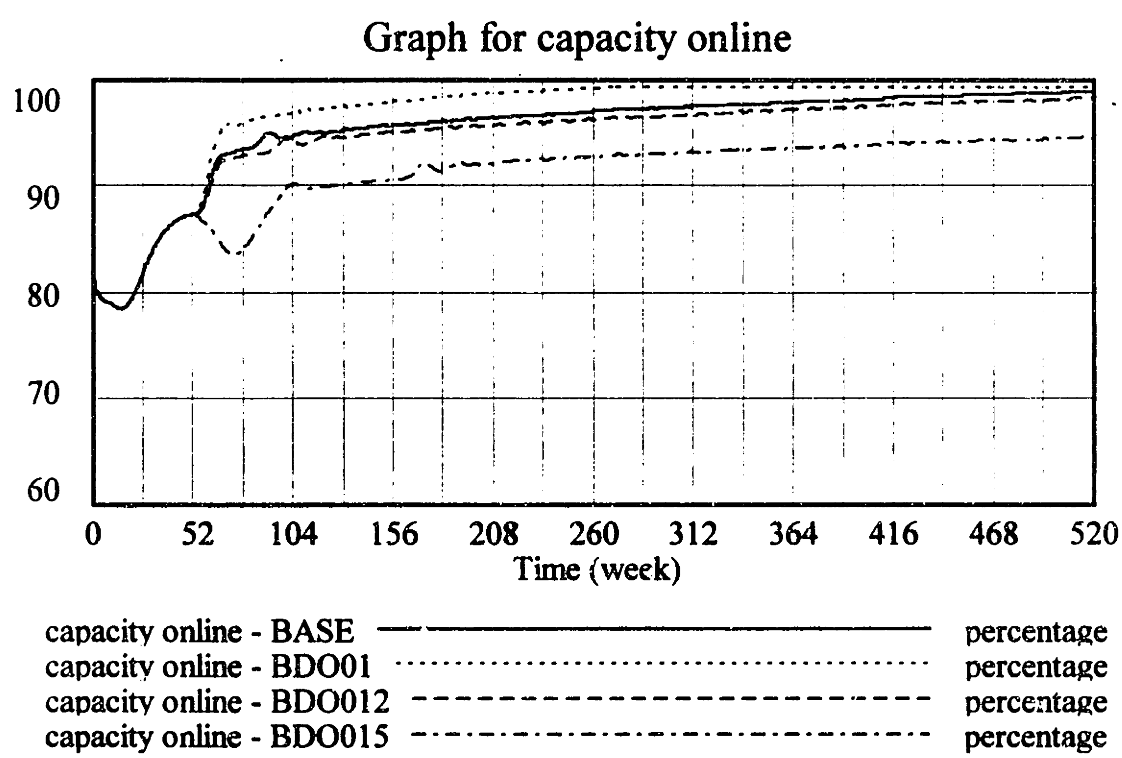
Graph for capacity online



Variable 2

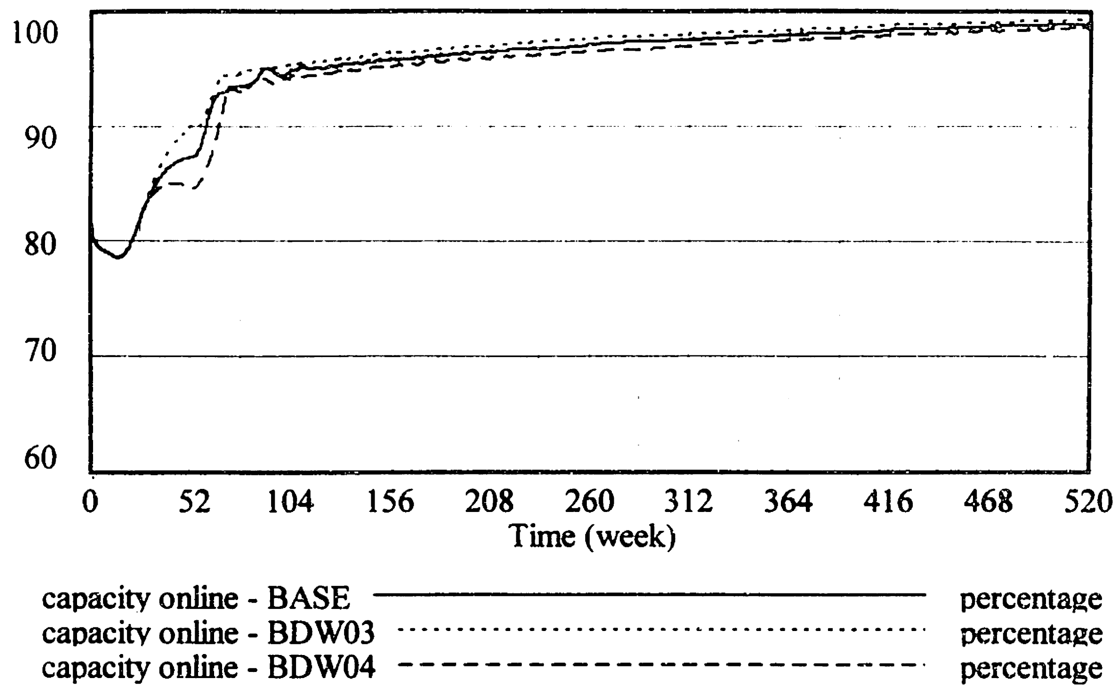


Variable 3



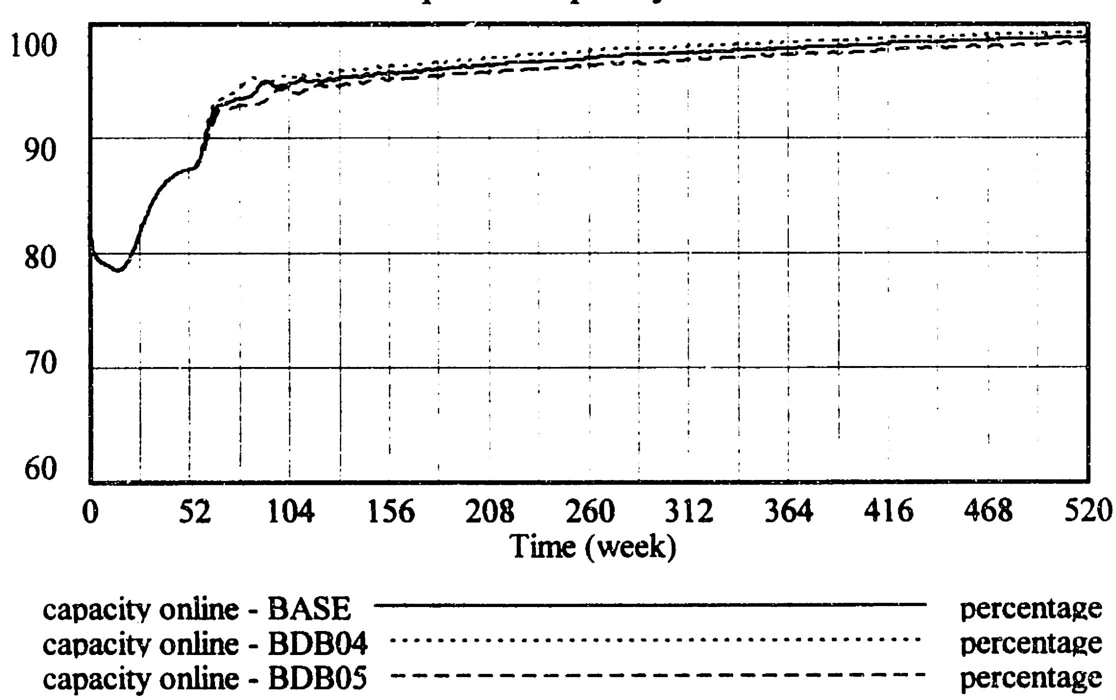
Variable 4

Graph for capacity online

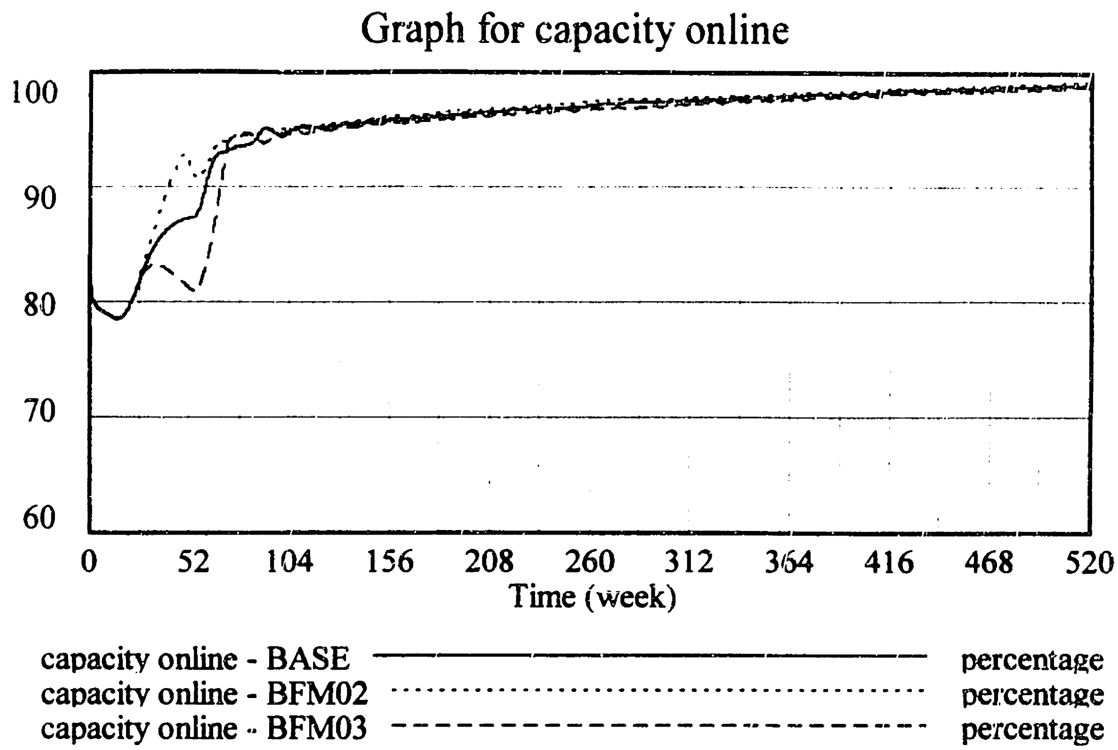


Variable 5

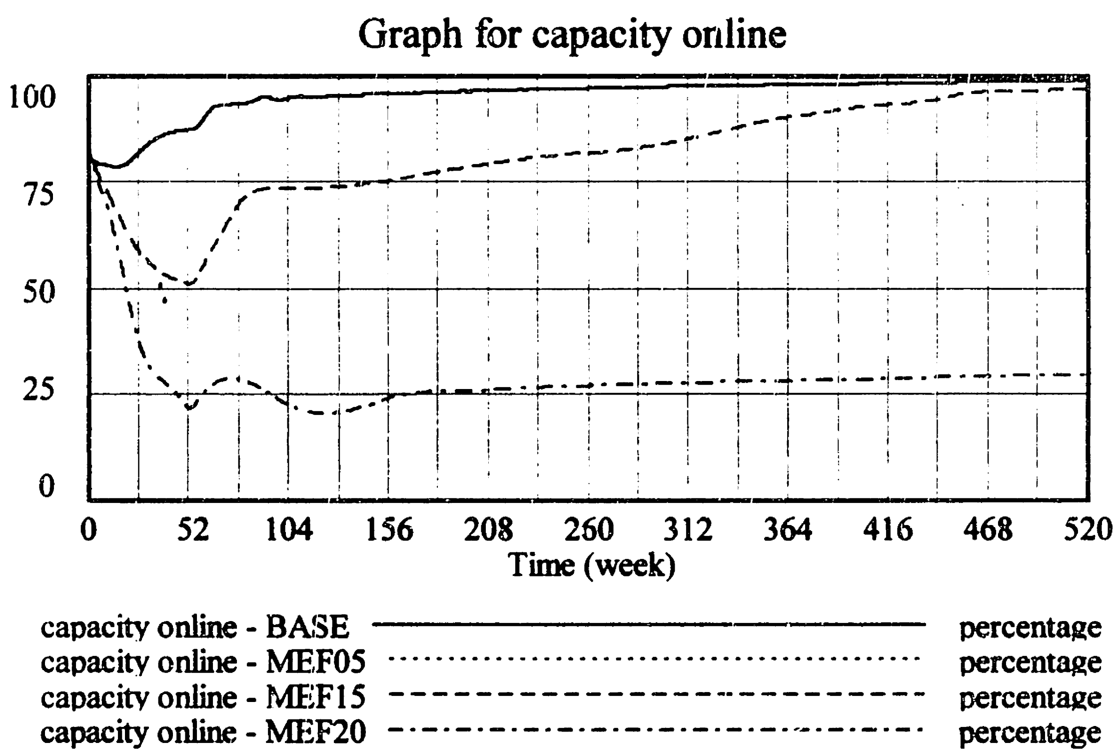
Graph for capacity online



Variable 6

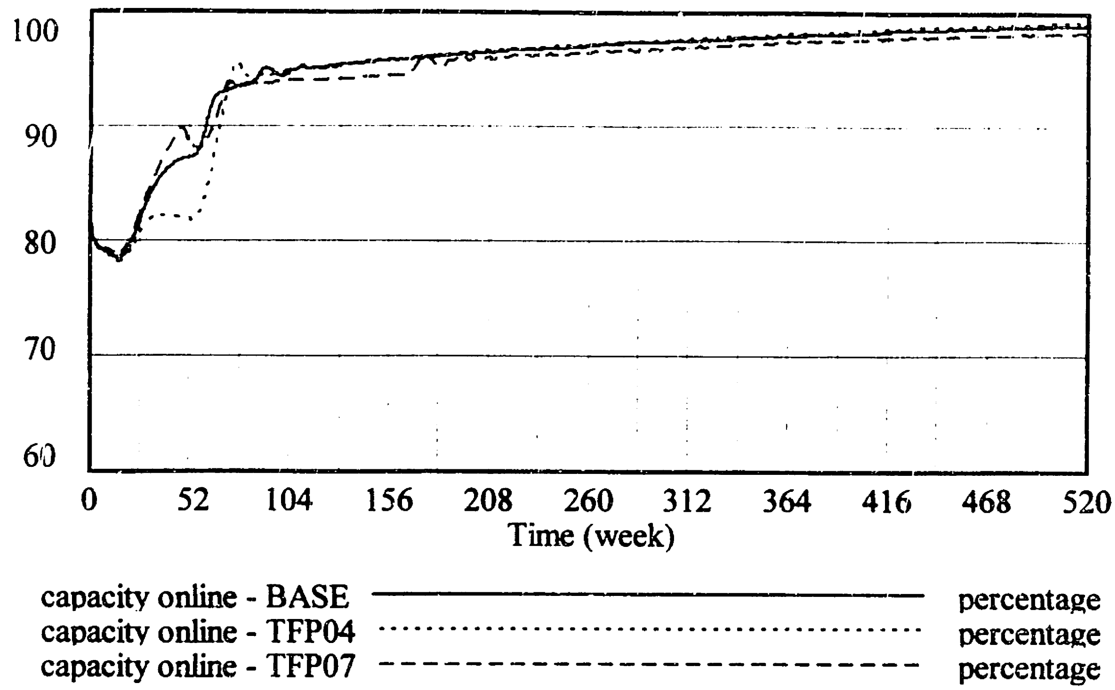


Variable 7



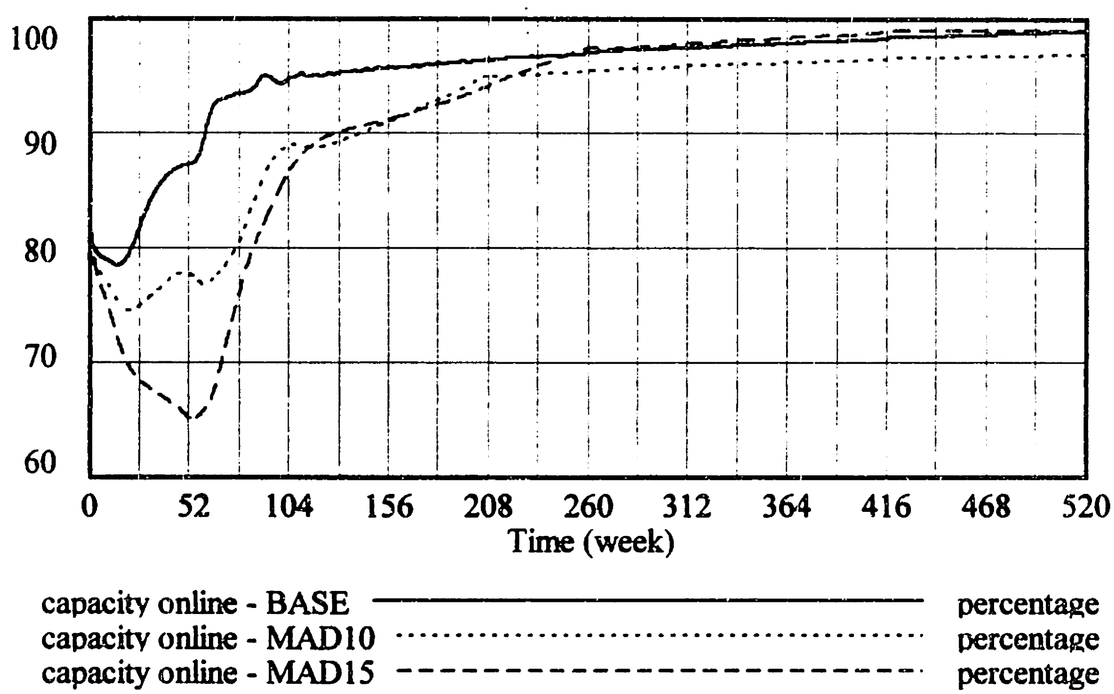
Variable 8

Graph for capacity online



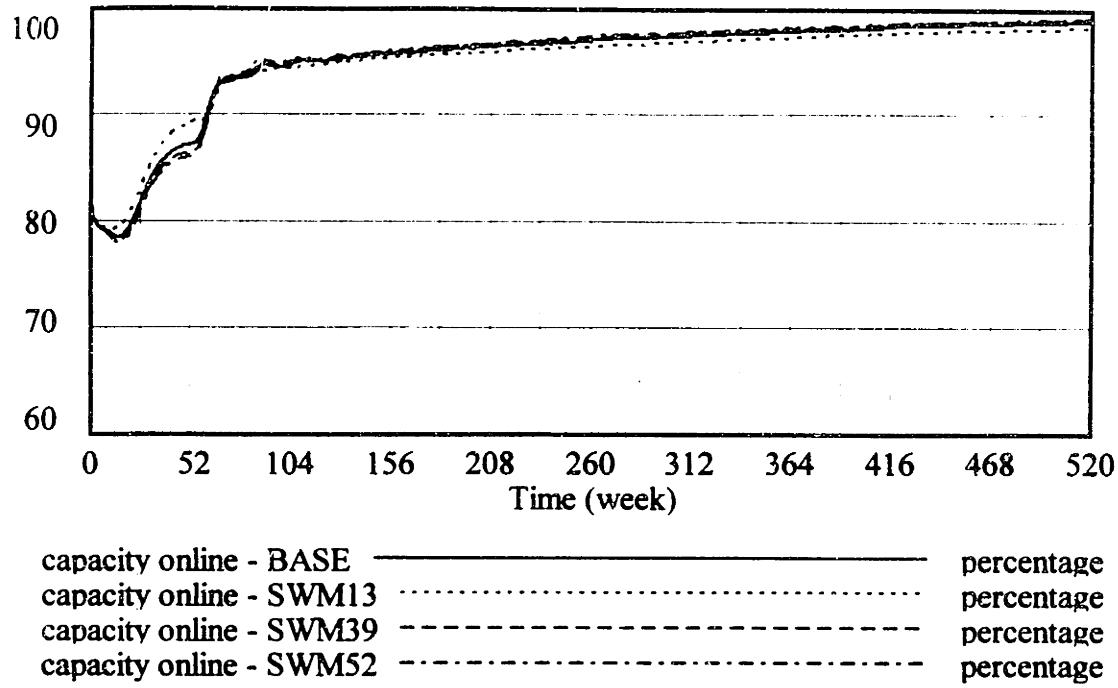
Variable 9

Graph for capacity online



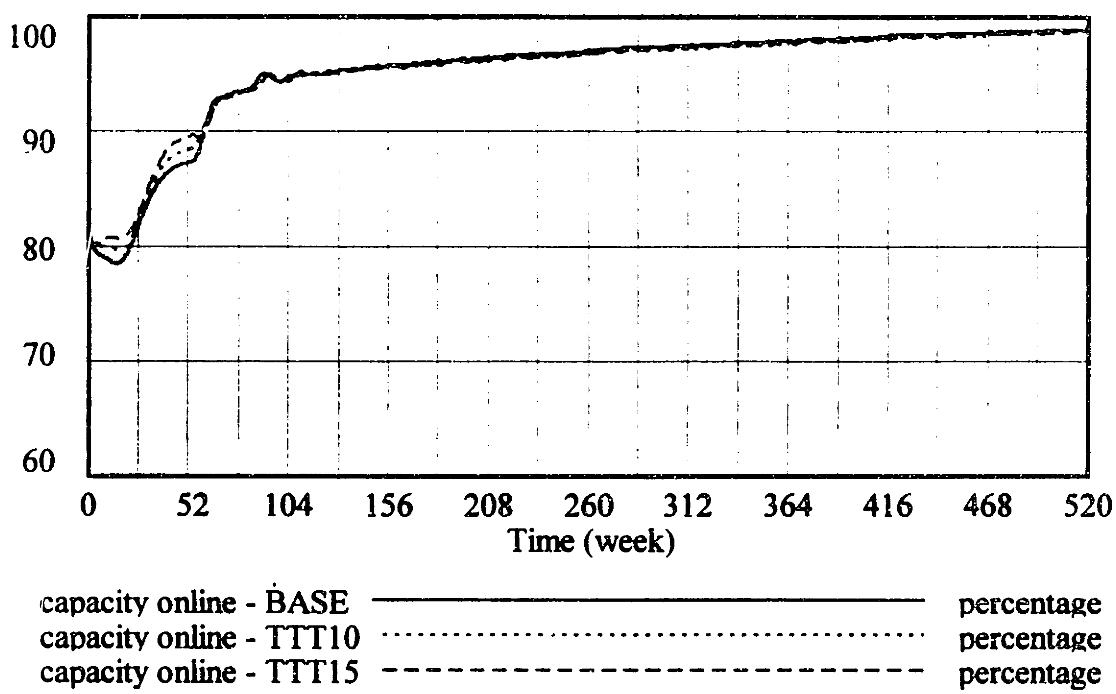
Variable 10

Graph for capacity online



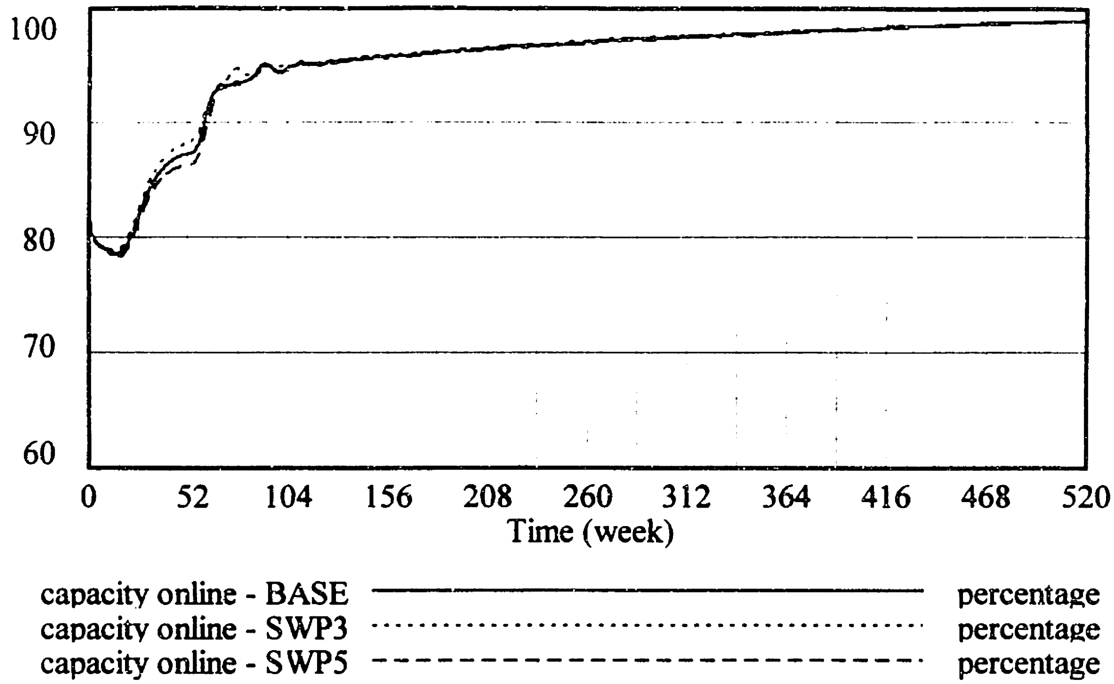
Variable 11

Graph for capacity online



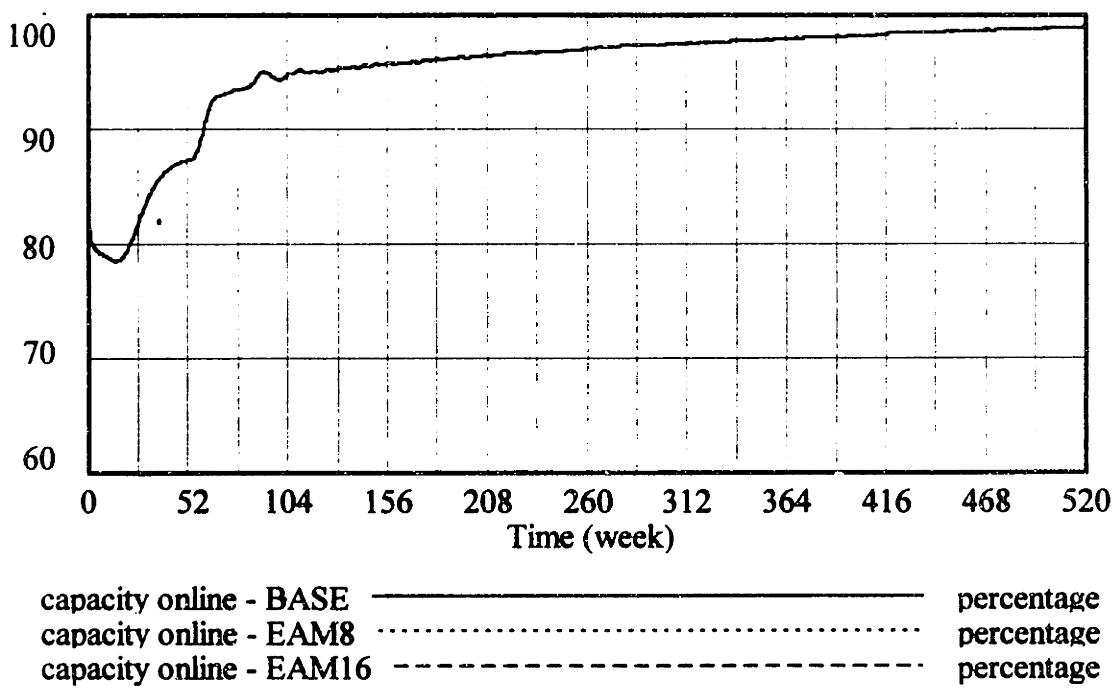
Variable 12

Graph for capacity online

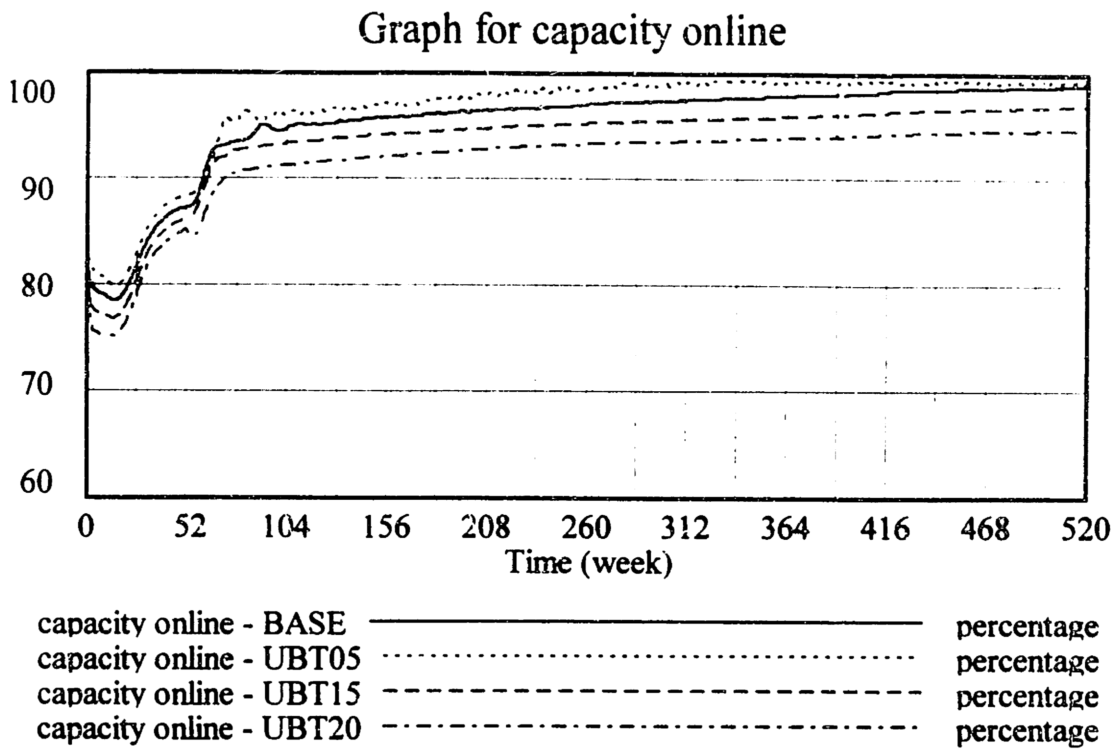


Variable 13

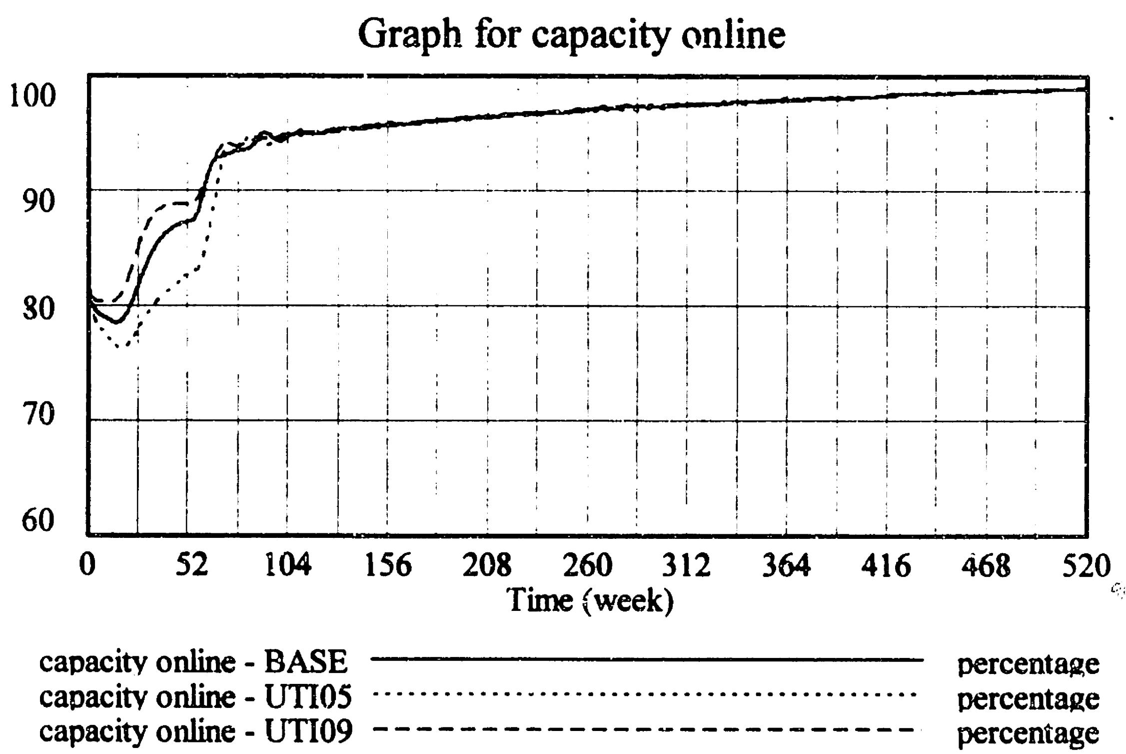
Graph for capacity online



Variable 14

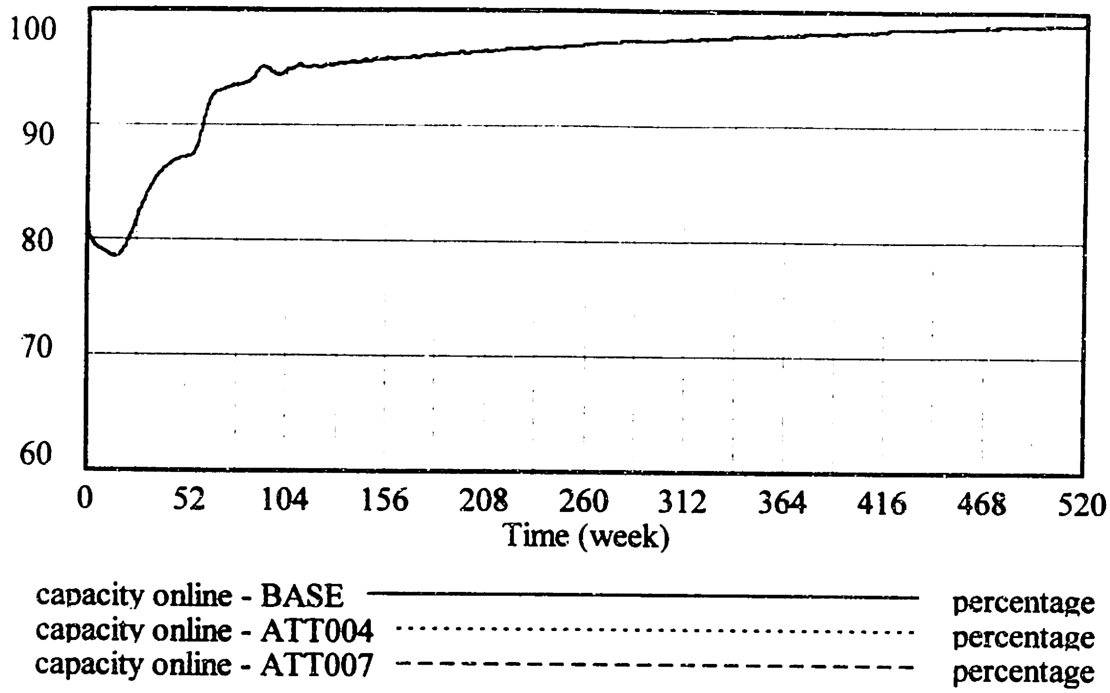


Variable 15



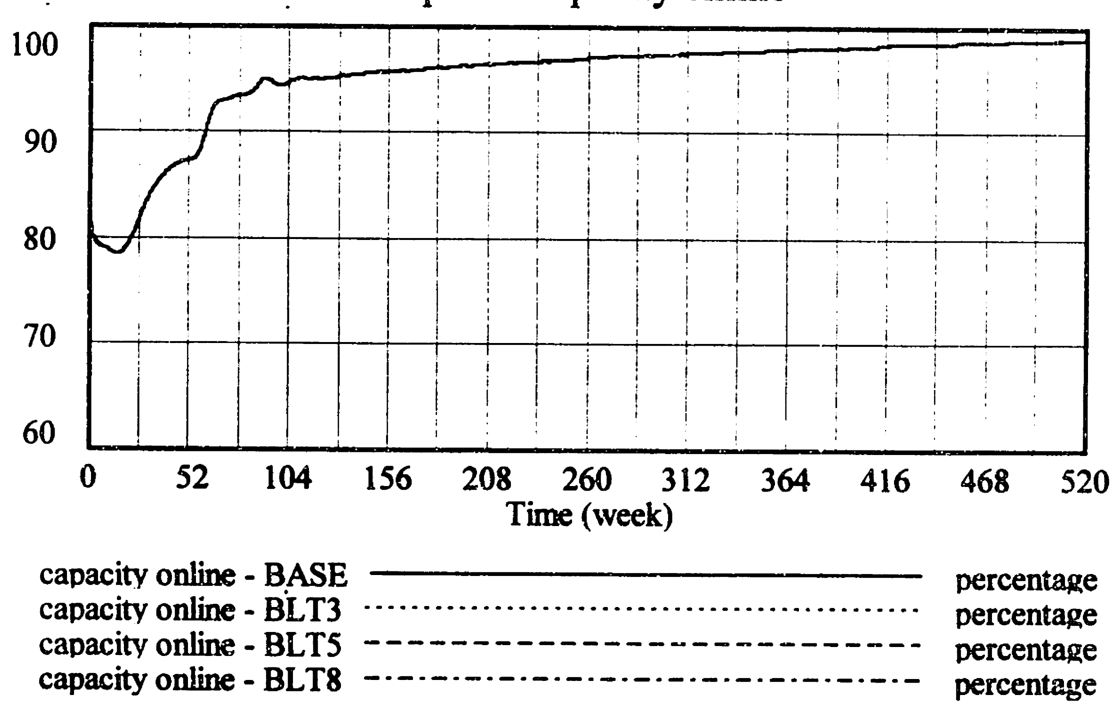
Variable 16

Graph for capacity online

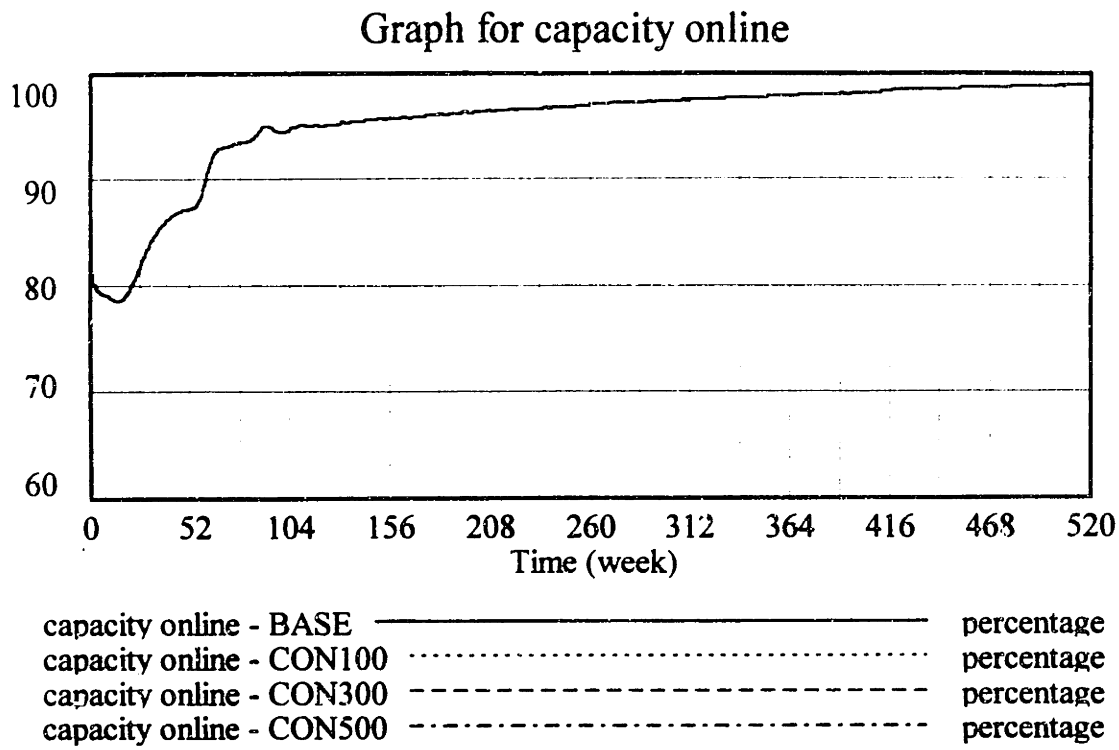


Variable 17

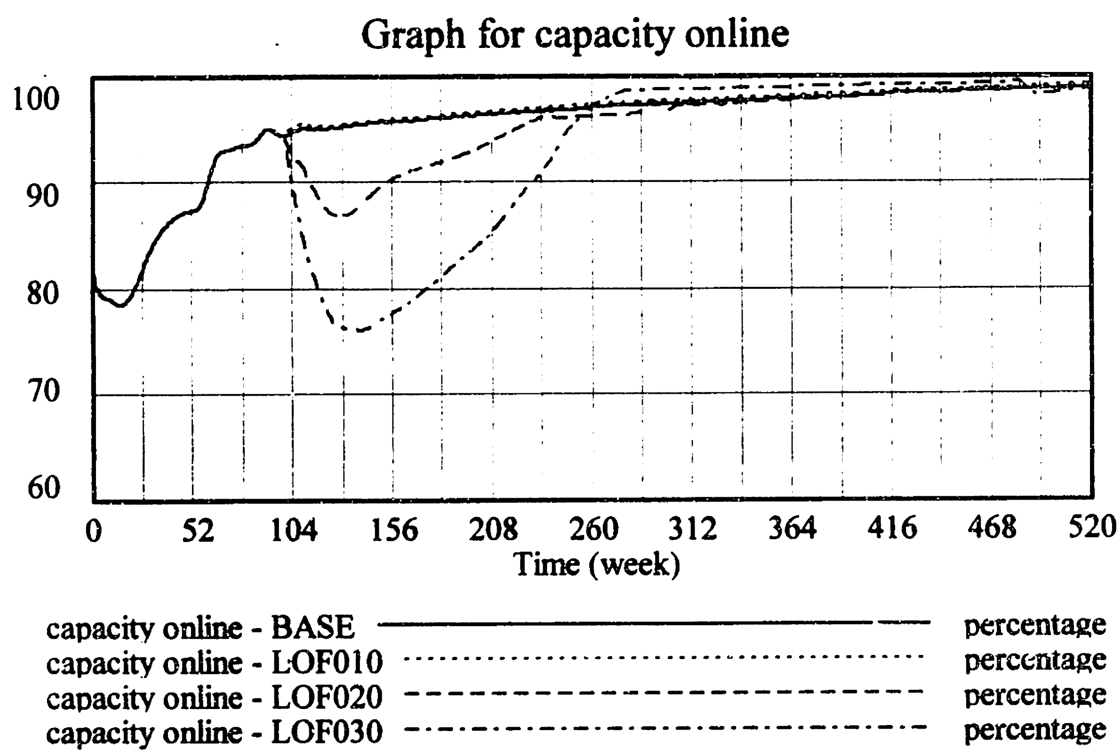
Graph for capacity online



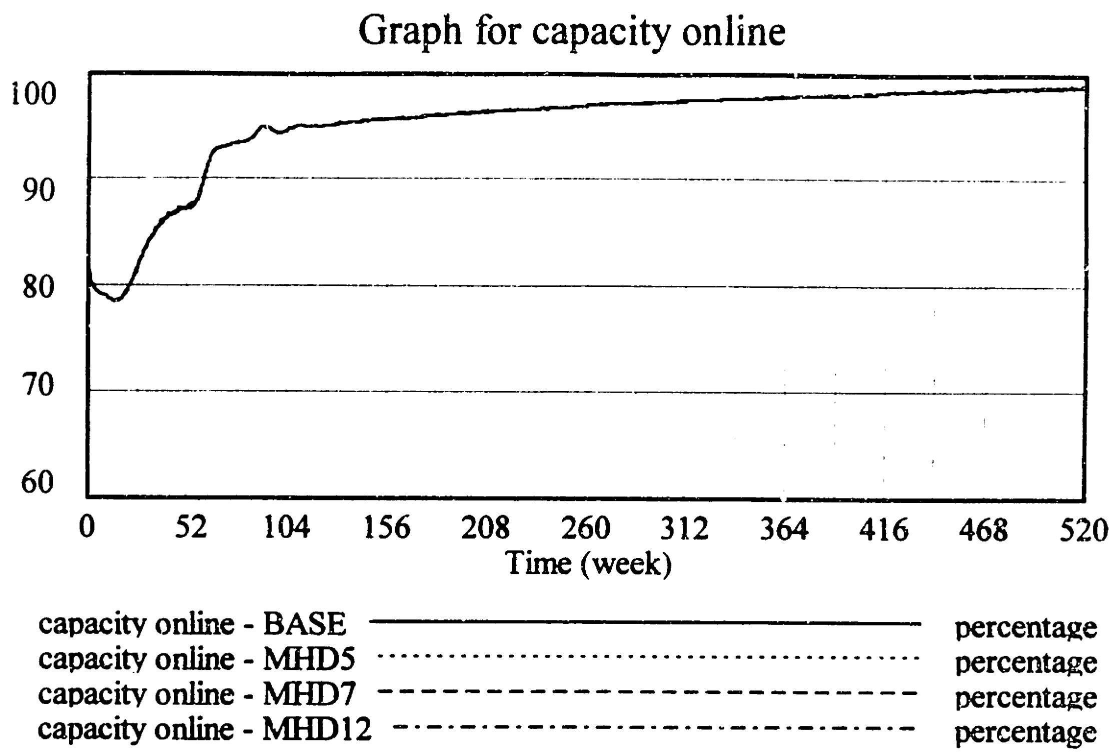
Variable 18



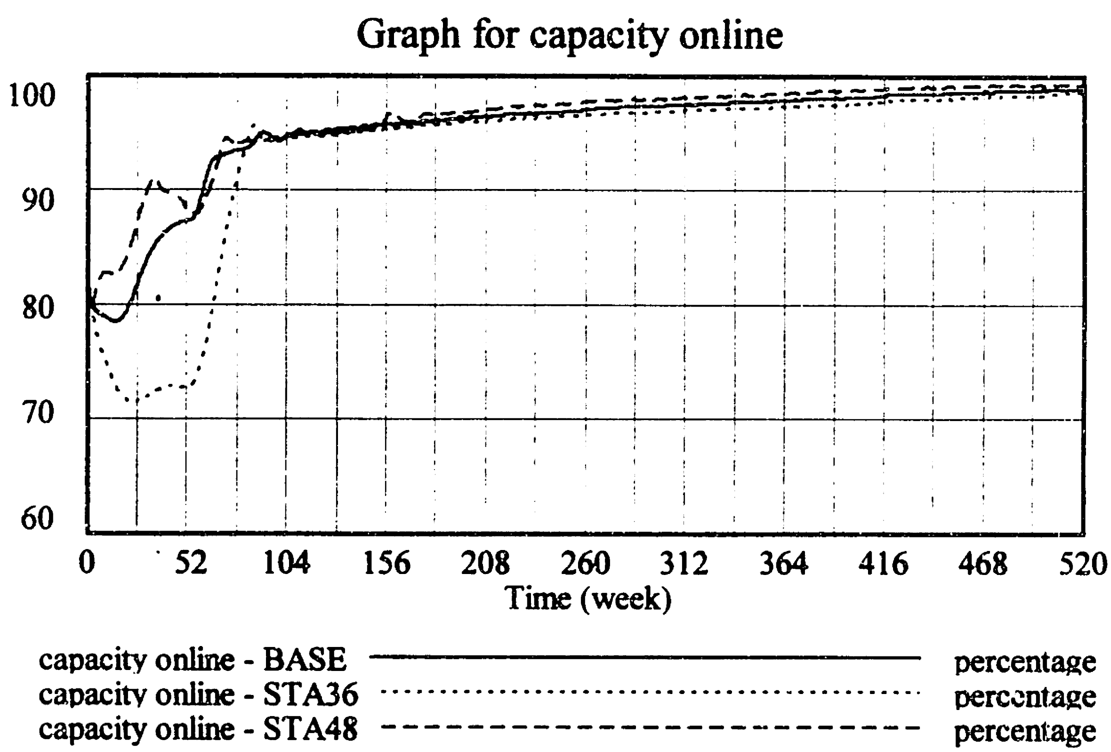
Variable 19



Variable 20

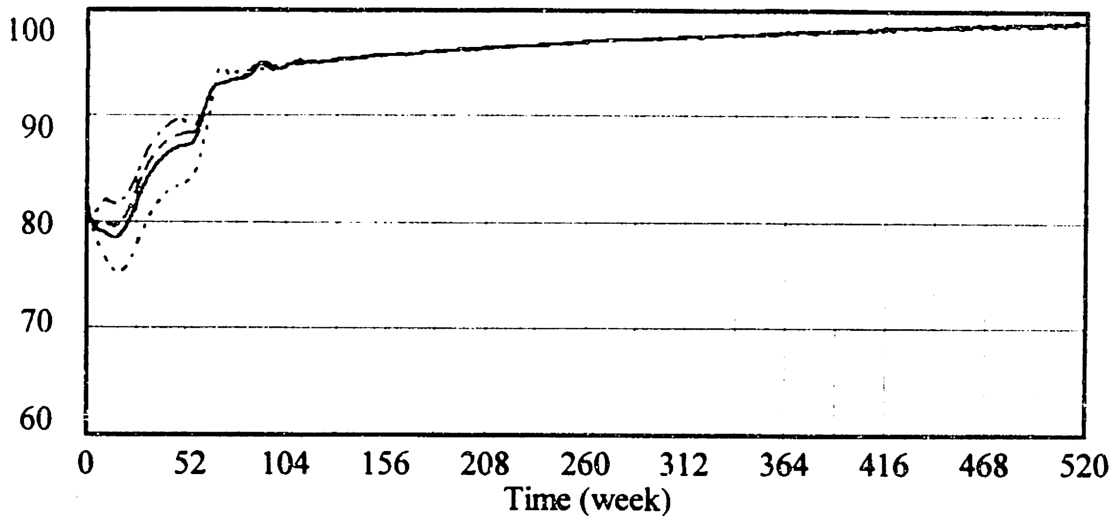


Variable 21



Variable 22

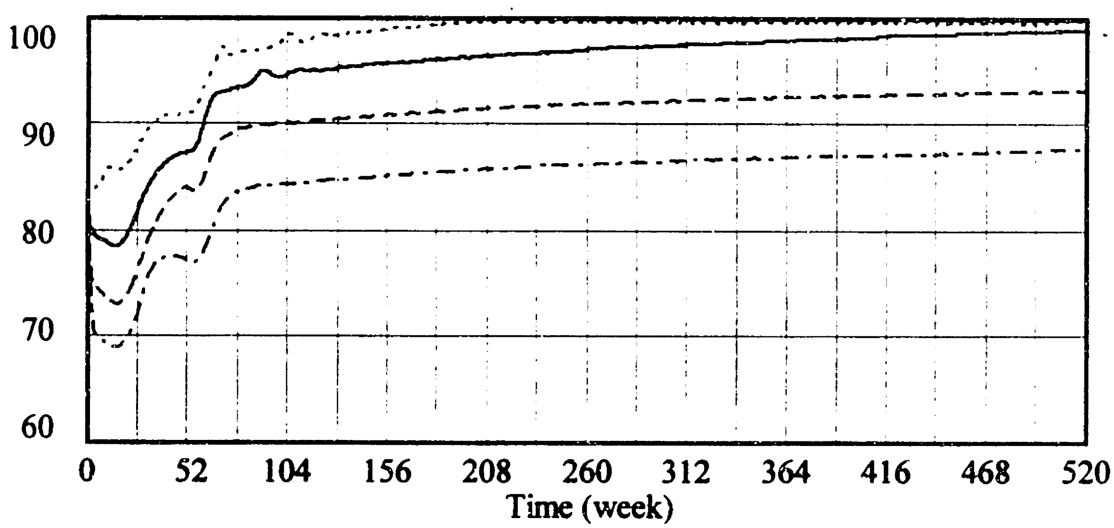
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - TRO005 ······· percentage
capacity online - TRO0125 - - - - percentage
capacity online - TRO02 -·-·-·- percentage

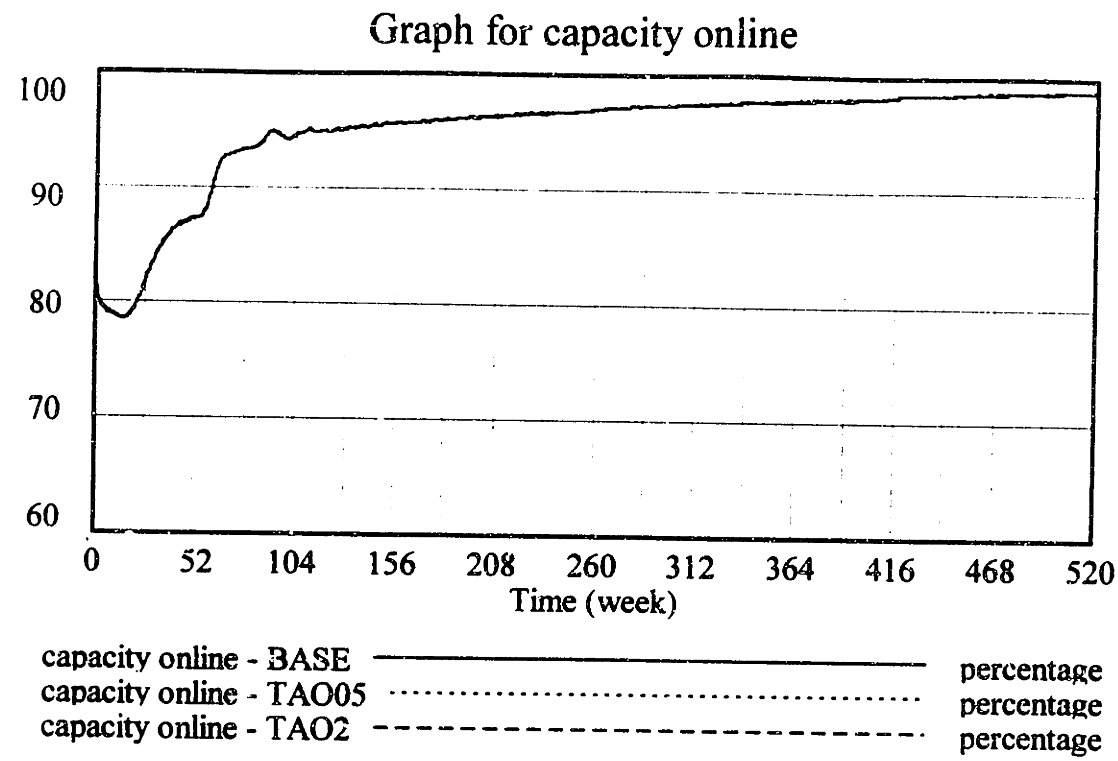
Variable 23

Graph for capacity online

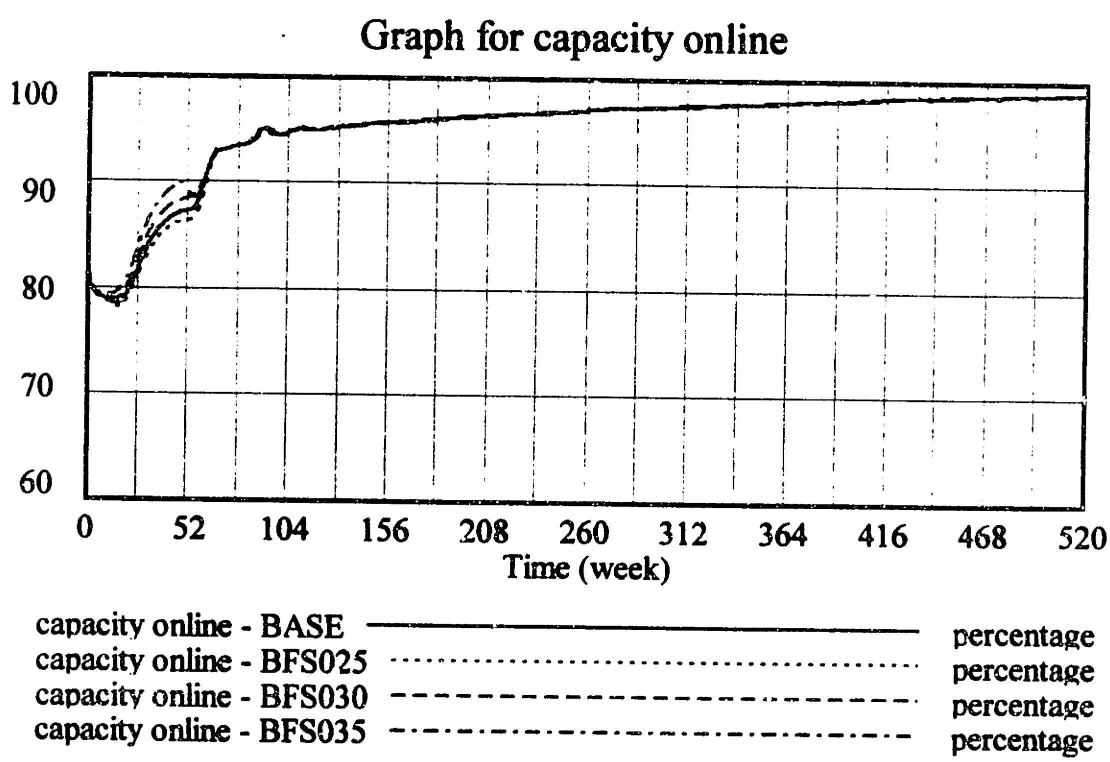


capacity online - BASE ——— percentage
capacity online - TWW1 ······· percentage
capacity online - TWW3 - - - - percentage
capacity online - TWW4 -·-·-·- percentage

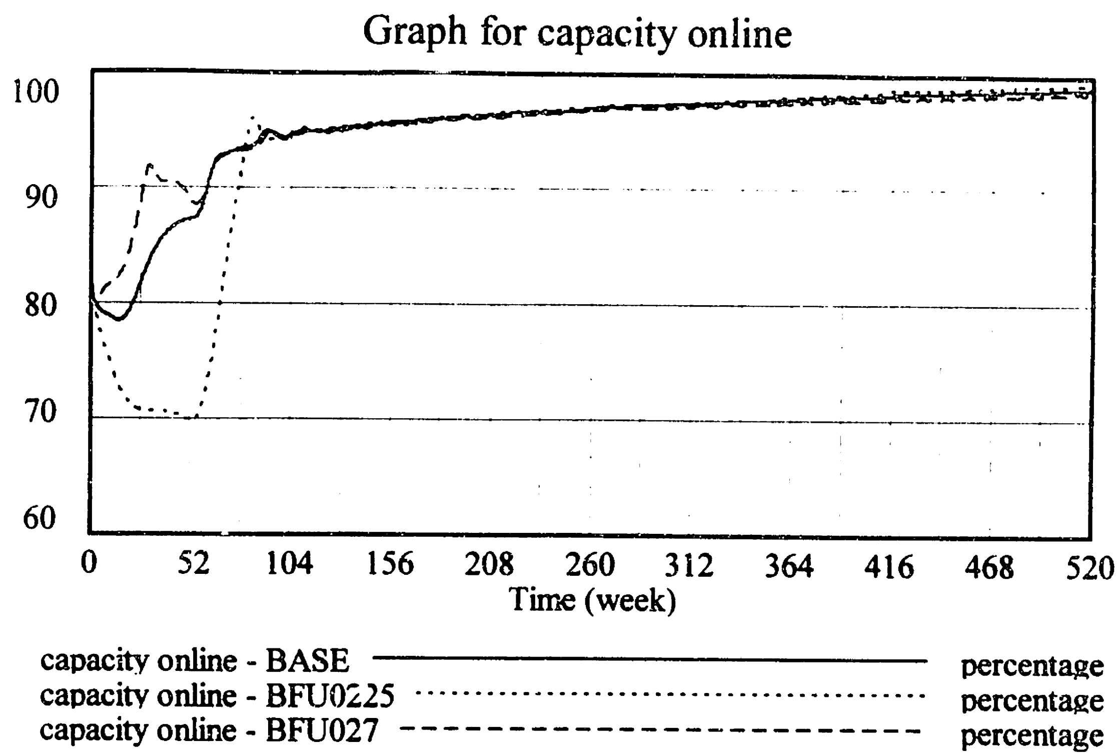
Variable 24



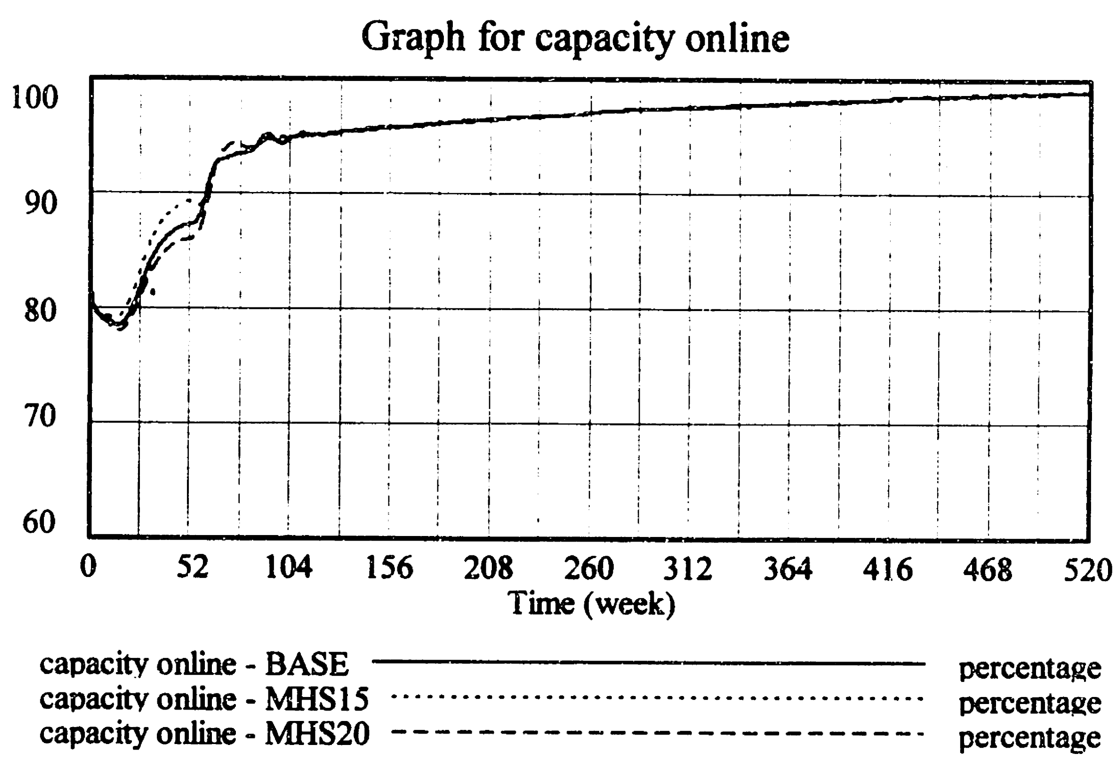
Variable 25



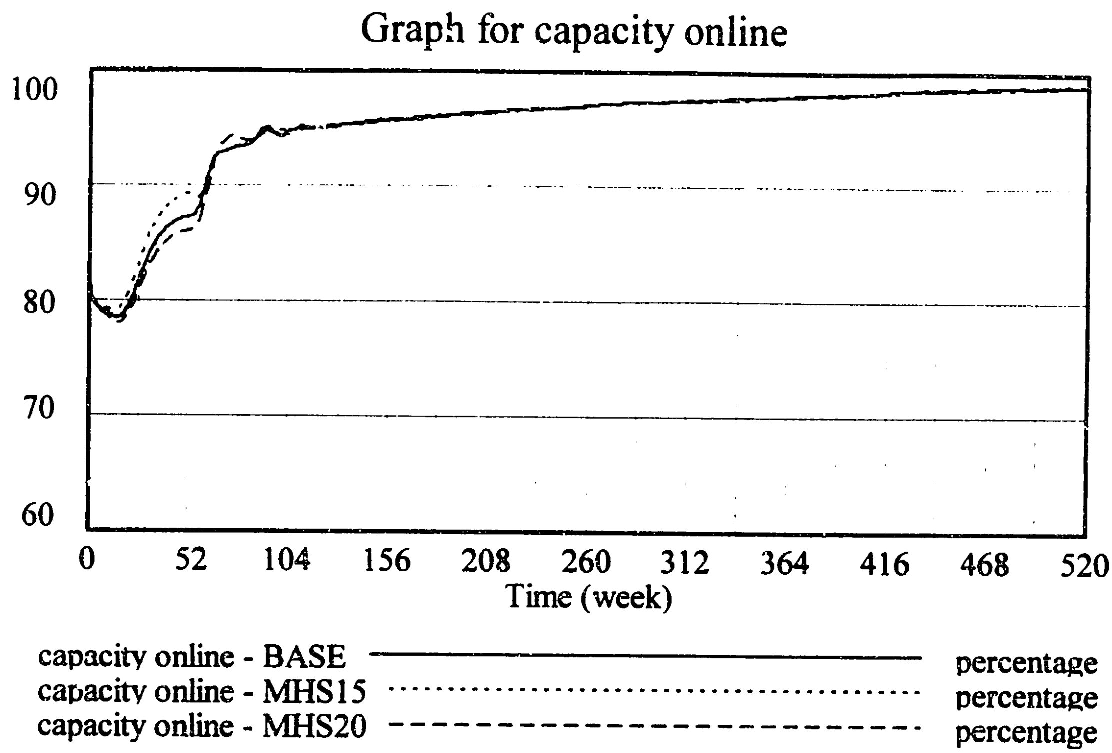
Variable 26



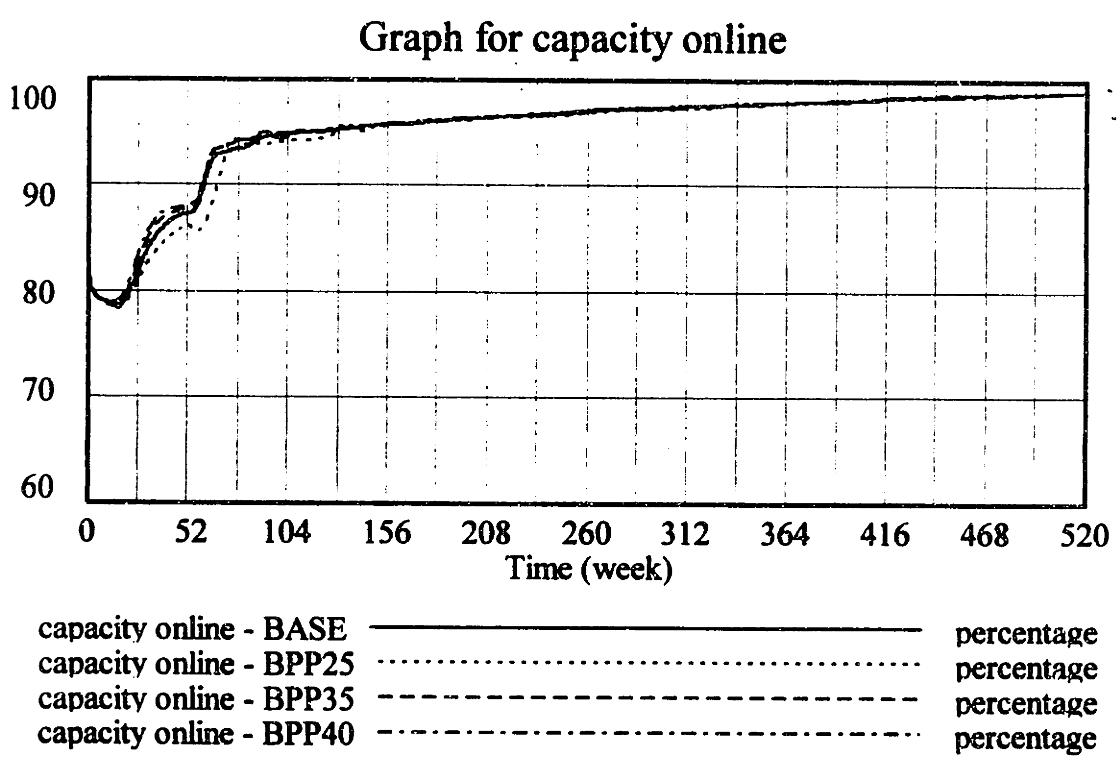
Variable 27



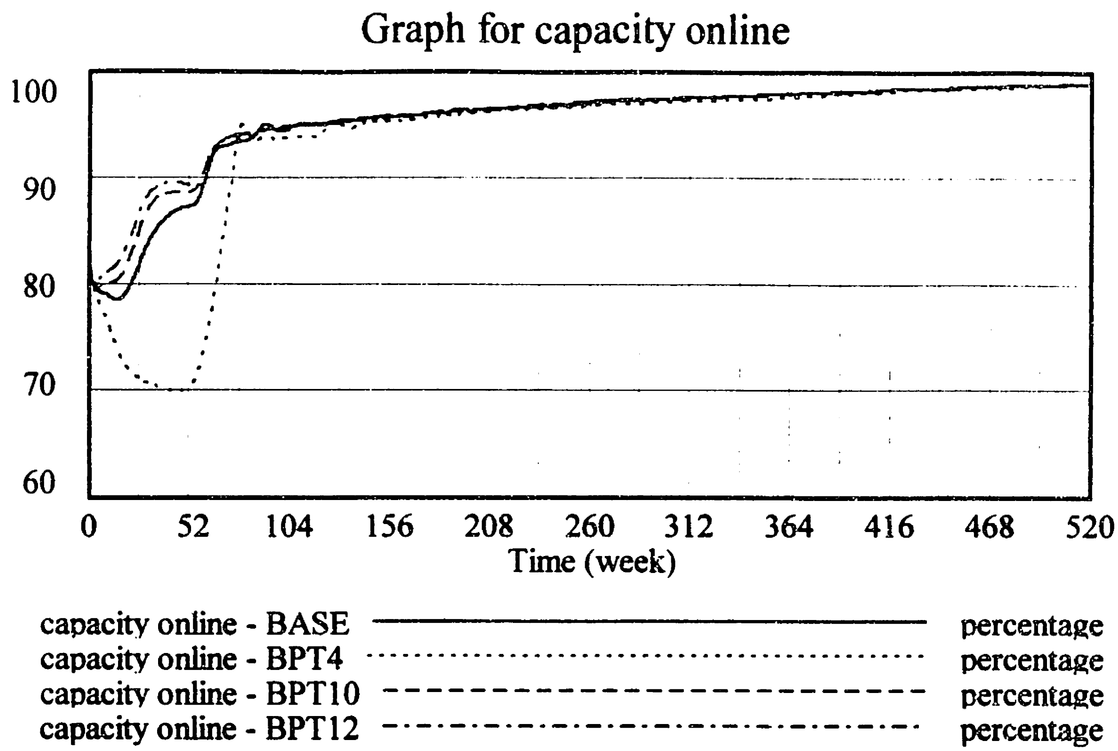
Variable 28



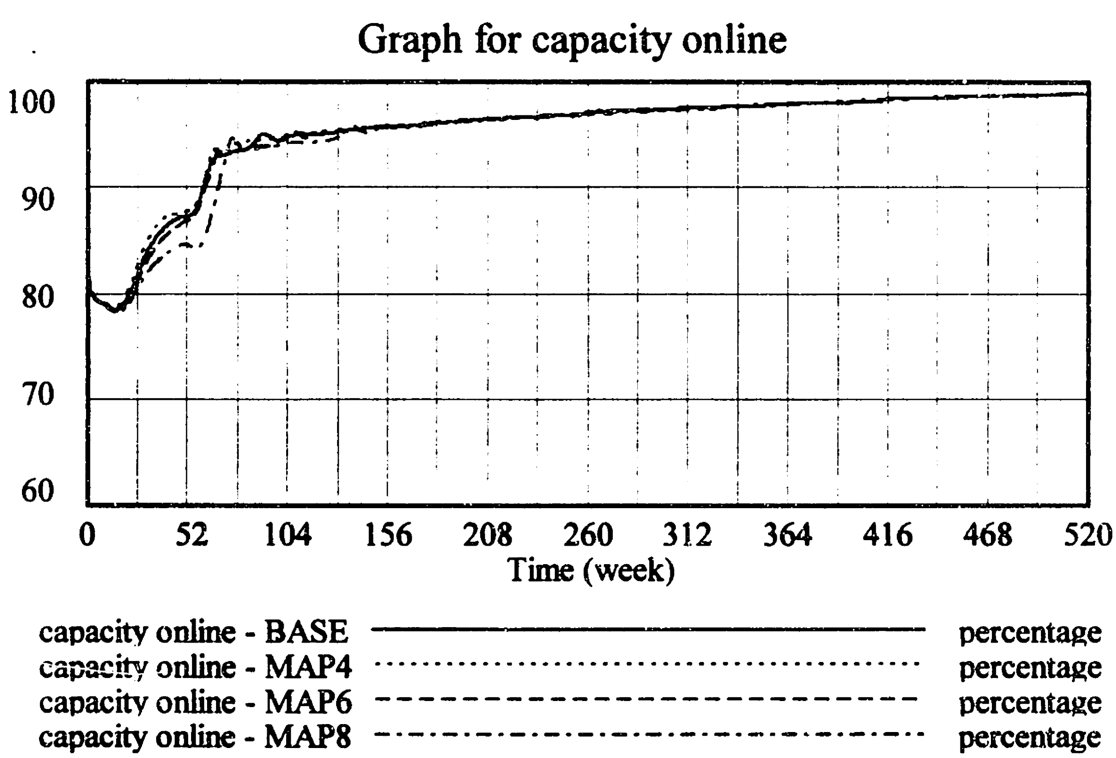
Variable 29



Variable 30

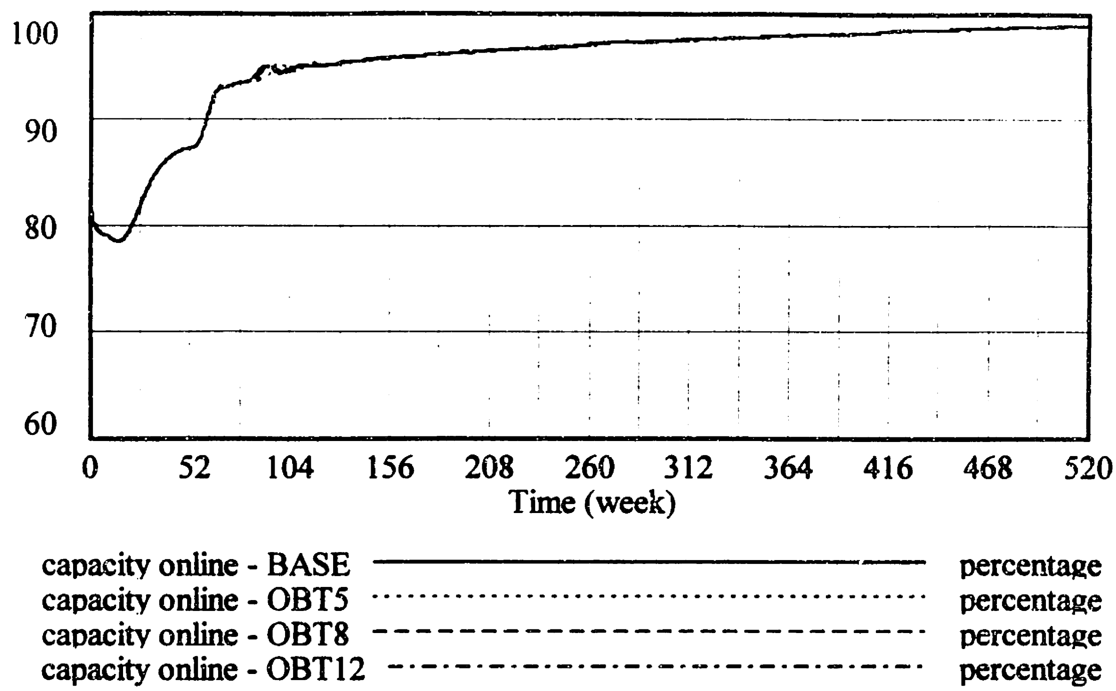


Variable 31



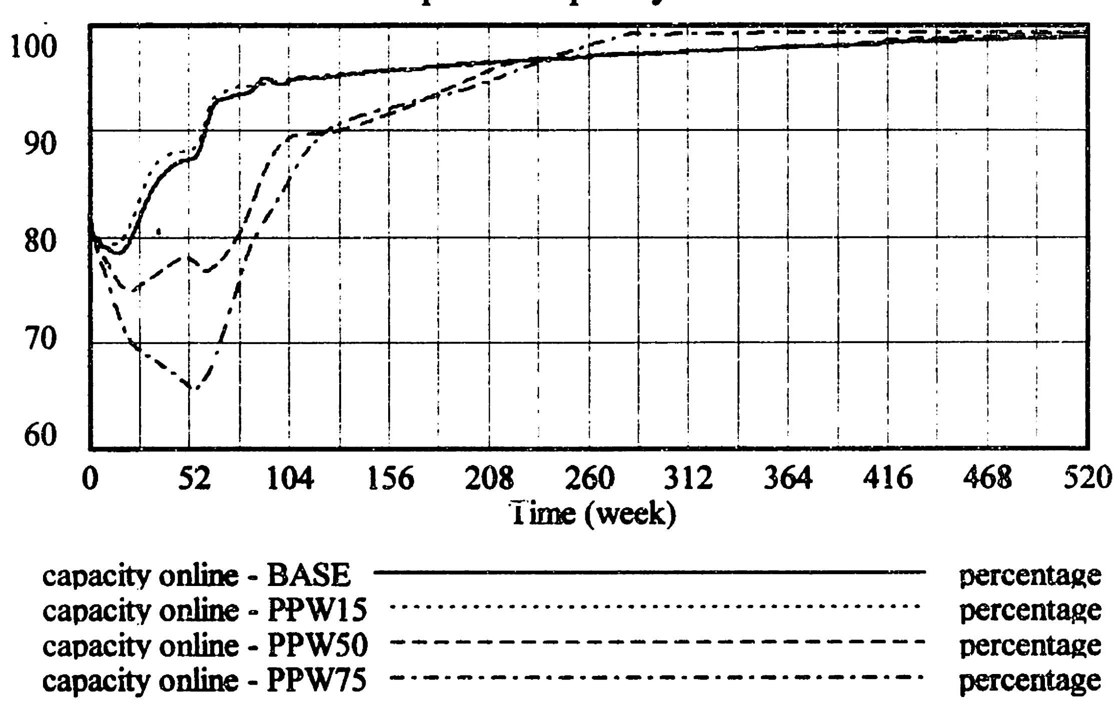
Variable 32

Graph for capacity online



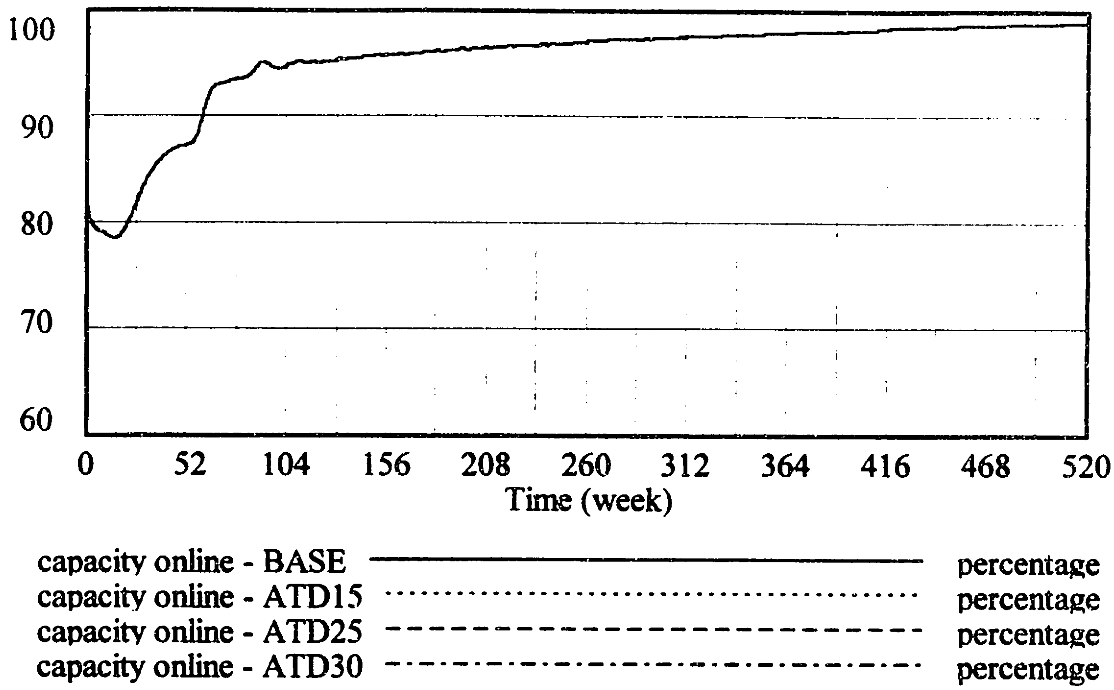
Variable 33

Graph for capacity online



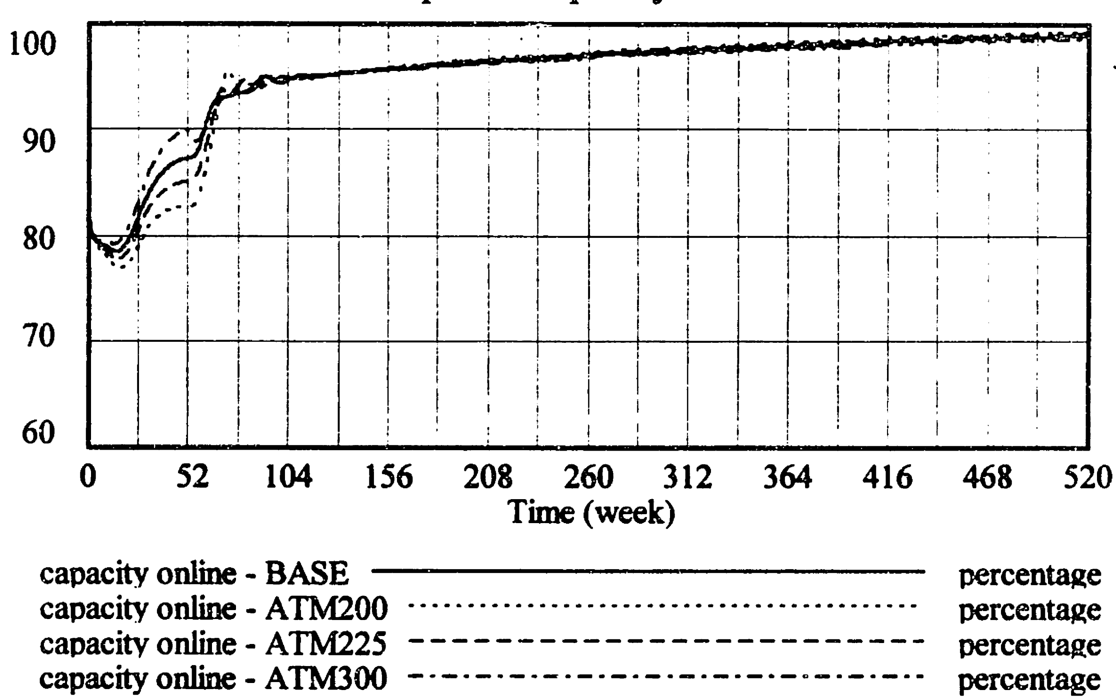
Variable 34

Graph for capacity online



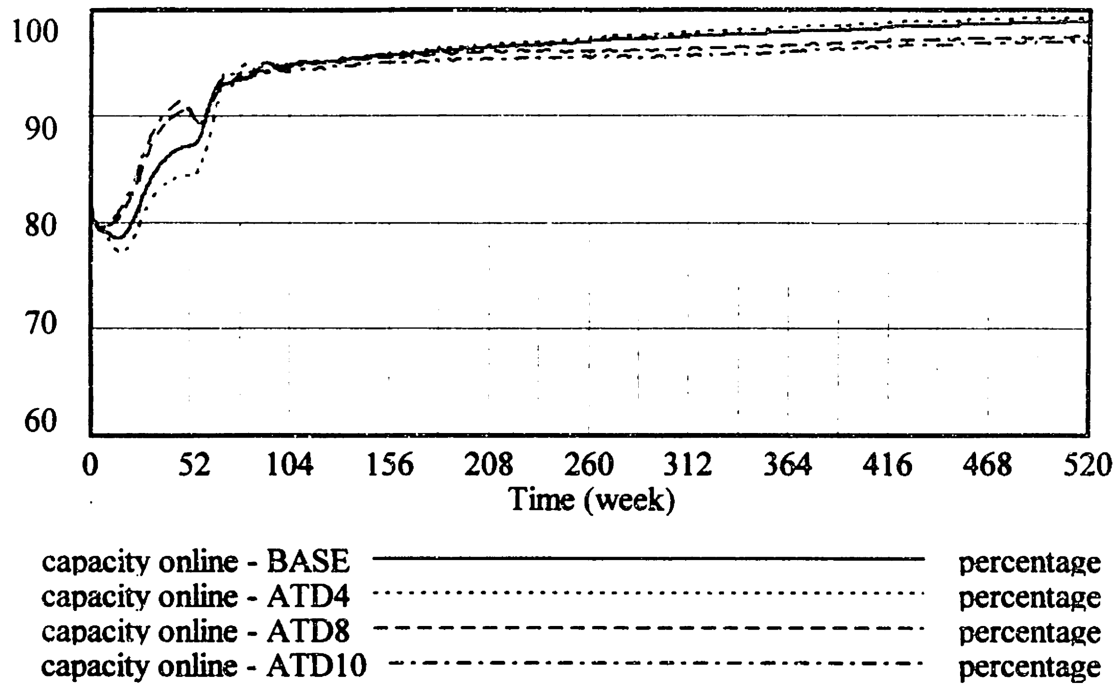
Variable 35

Graph for capacity online



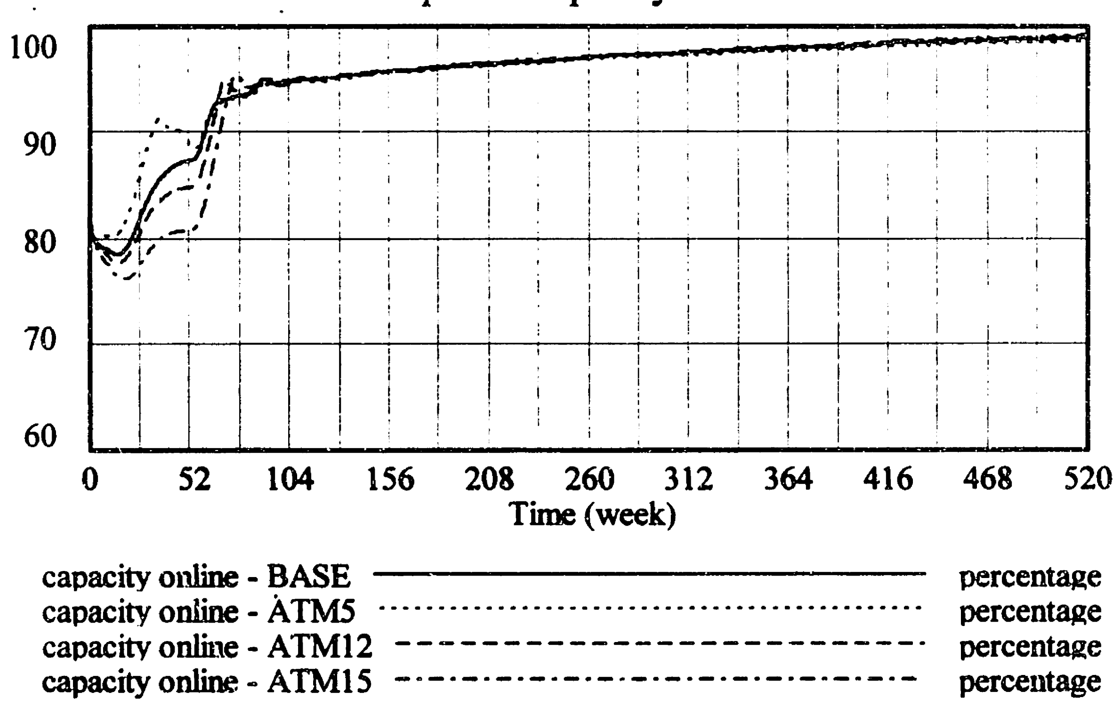
Variable 36

Graph for capacity online



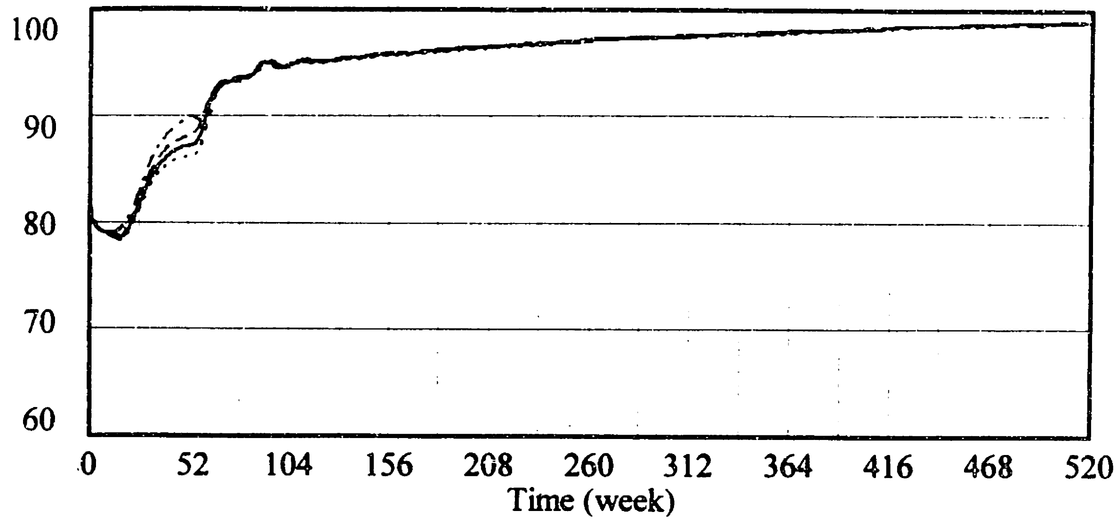
Variable 37

Graph for capacity online



Variable 38

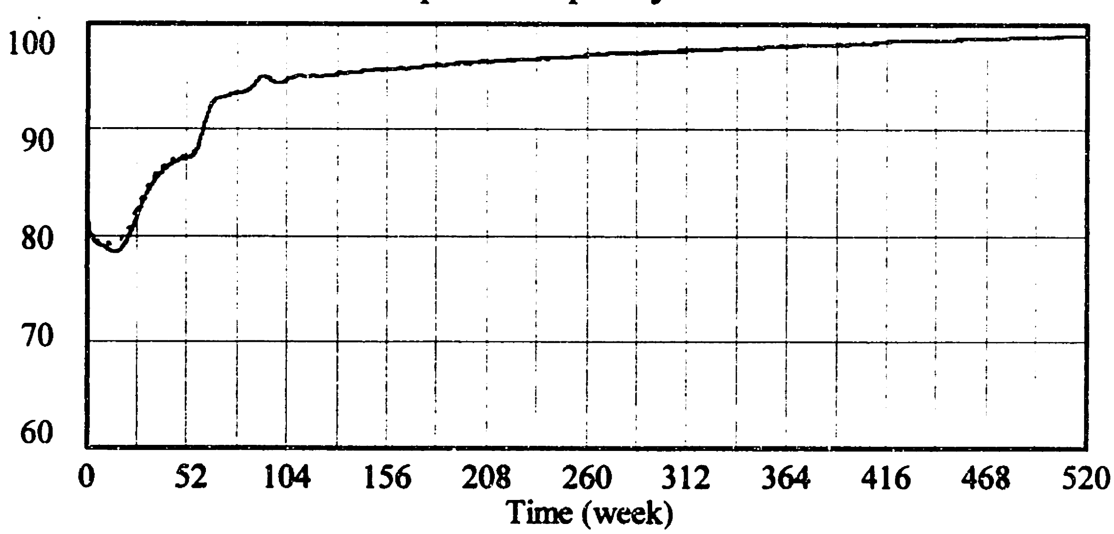
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - FDR010 ········ percentage
capacity online - FDR020 - - - - percentage
capacity online - FDR030 -·-·-·- percentage

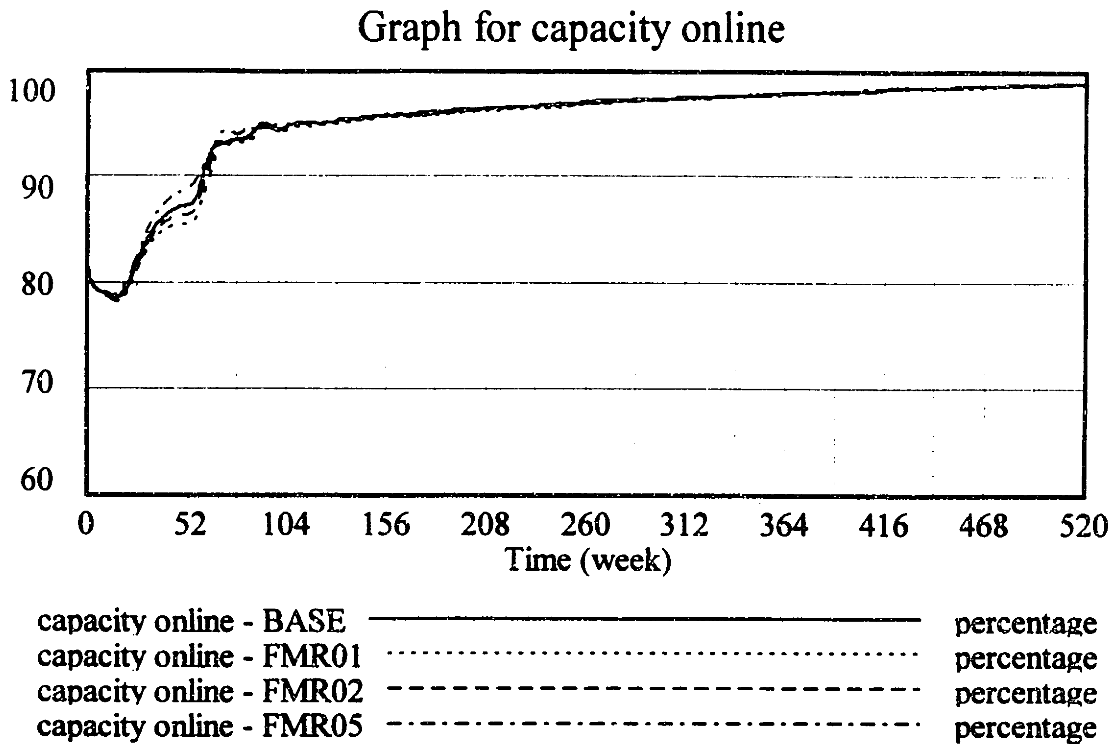
Variable 39

Graph for capacity online

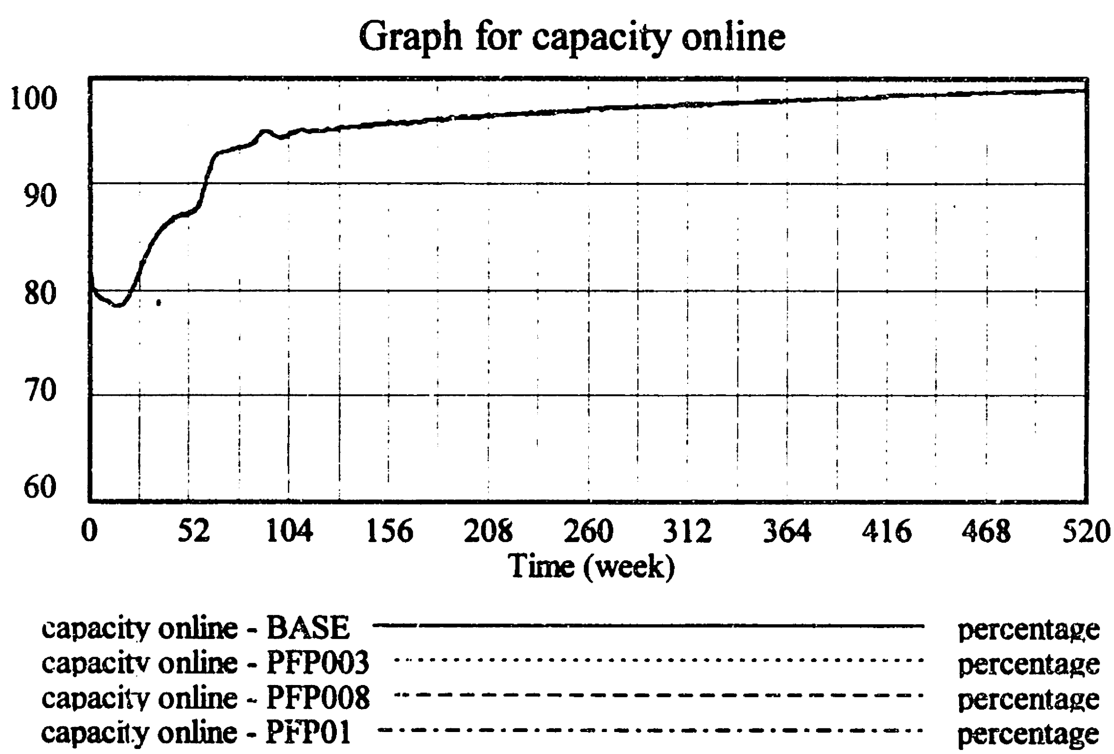


capacity online - BASE ——— percentage
capacity online - FEI03 ········ percentage
capacity online - FEI05 - - - - percentage
capacity online - FEI09 -·-·-·- percentage

Variable 40

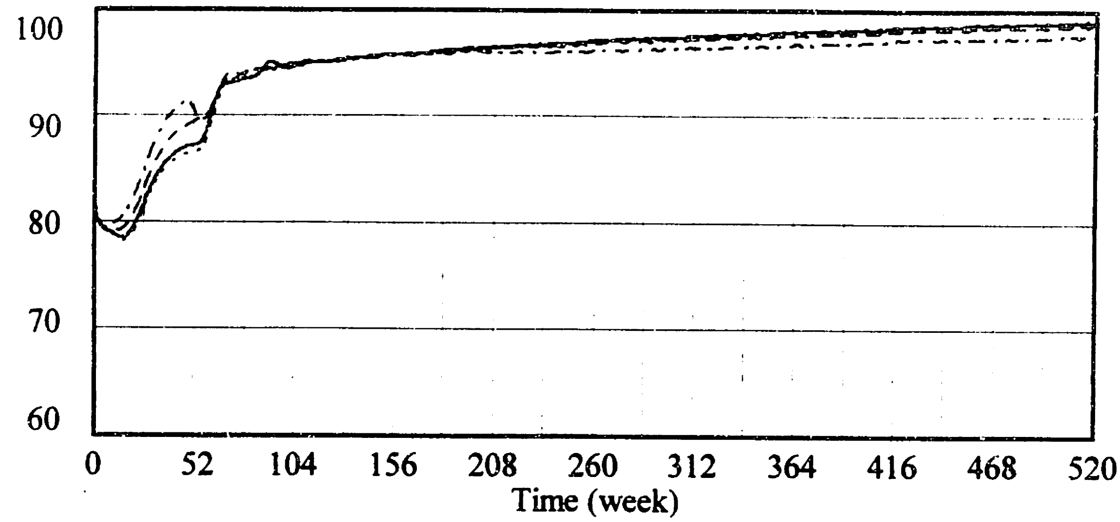


Variable 41



Variable 42

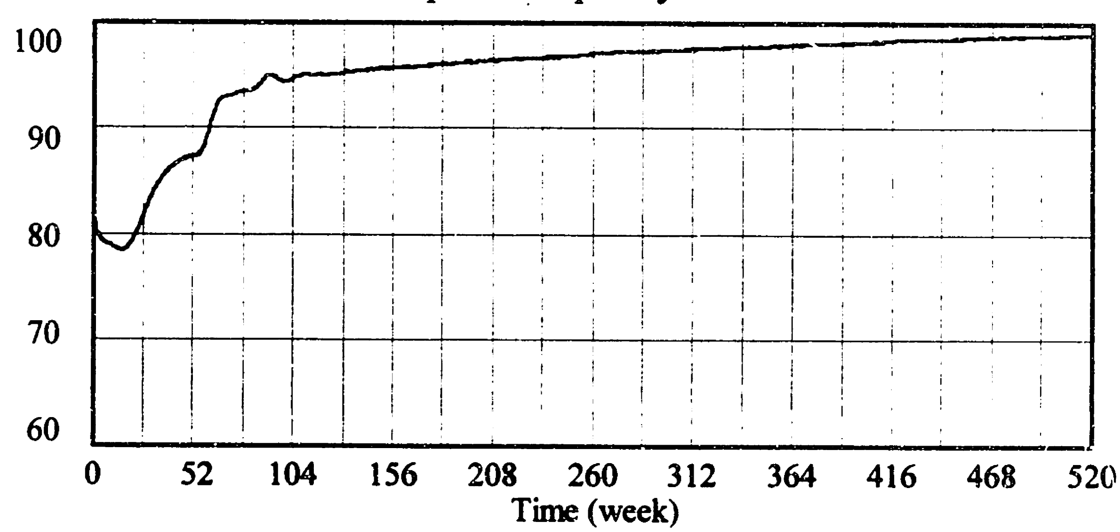
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - PMD01 ········ percentage
capacity online - PMD03 - - - - percentage
capacity online - PMD05 -·-·-·- percentage

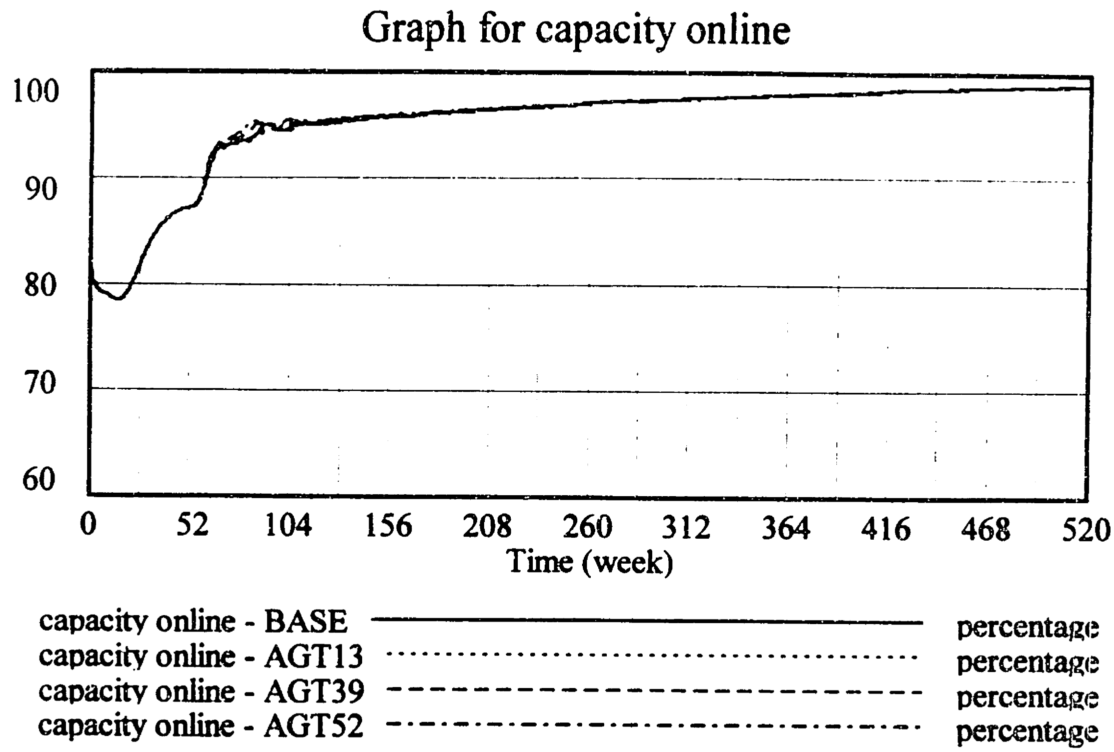
Variable 43

Graph for capacity online

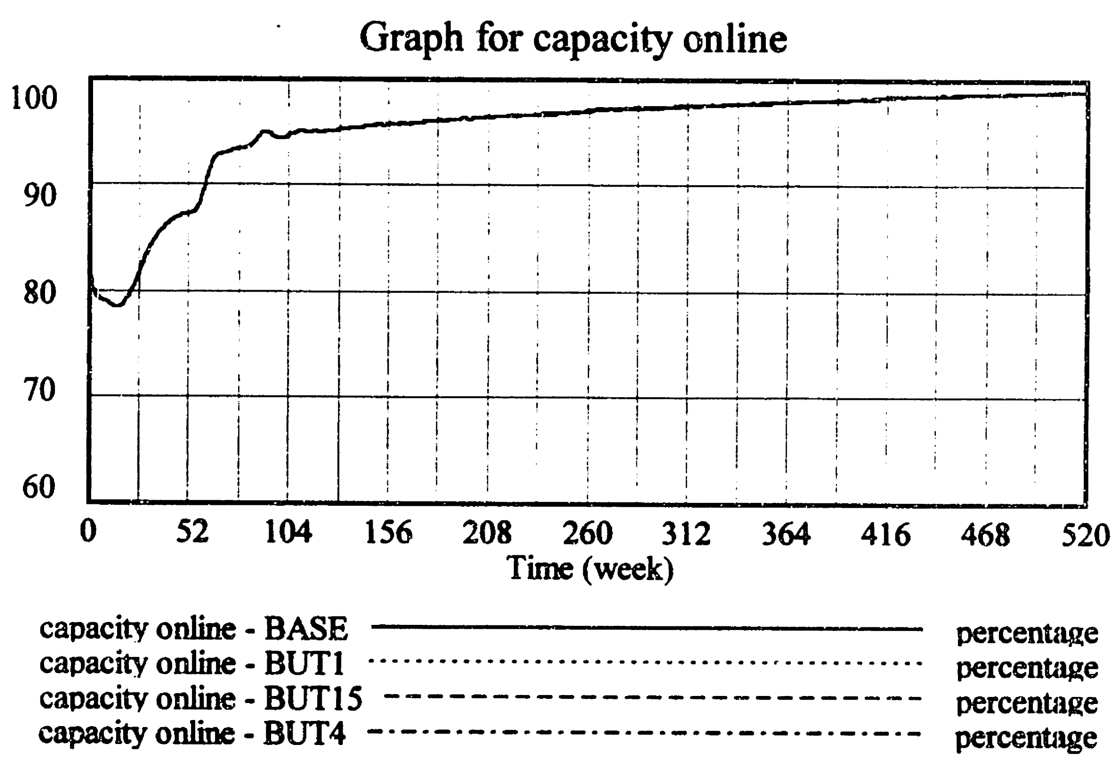


capacity online - BASE ———— percentage
capacity online - PMM001 ········ percentage
capacity online - PMM005 - - - - percentage
capacity online - PMM01 -·-·-·- percentage

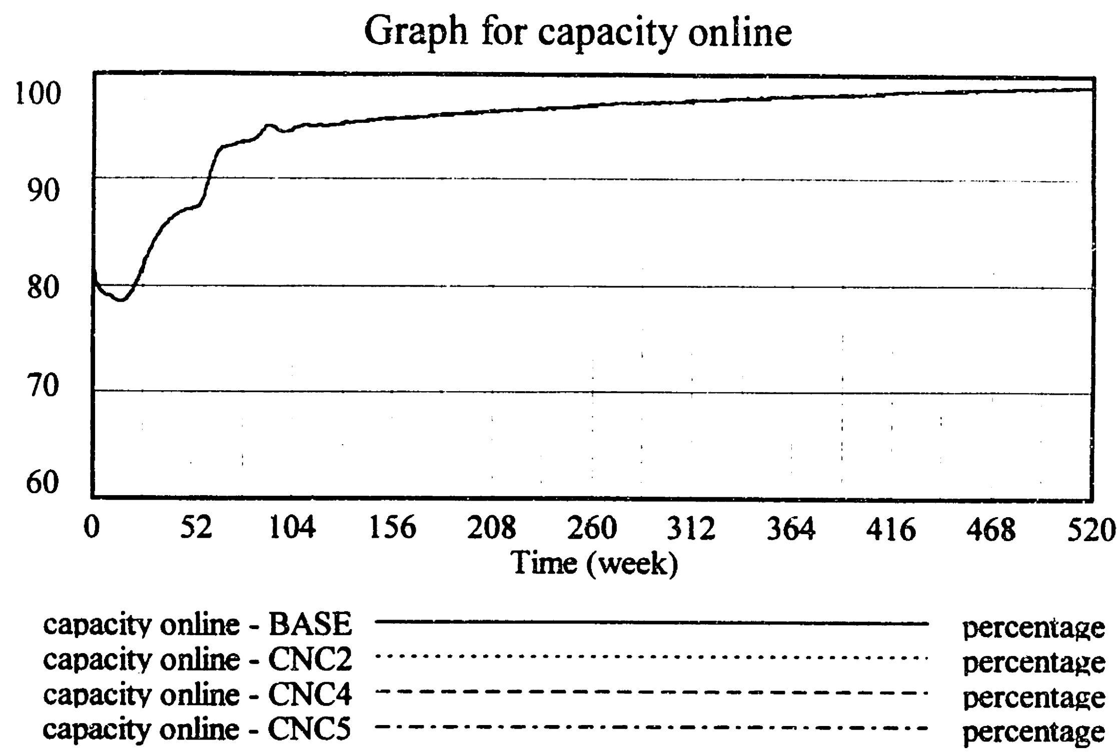
Variable 44



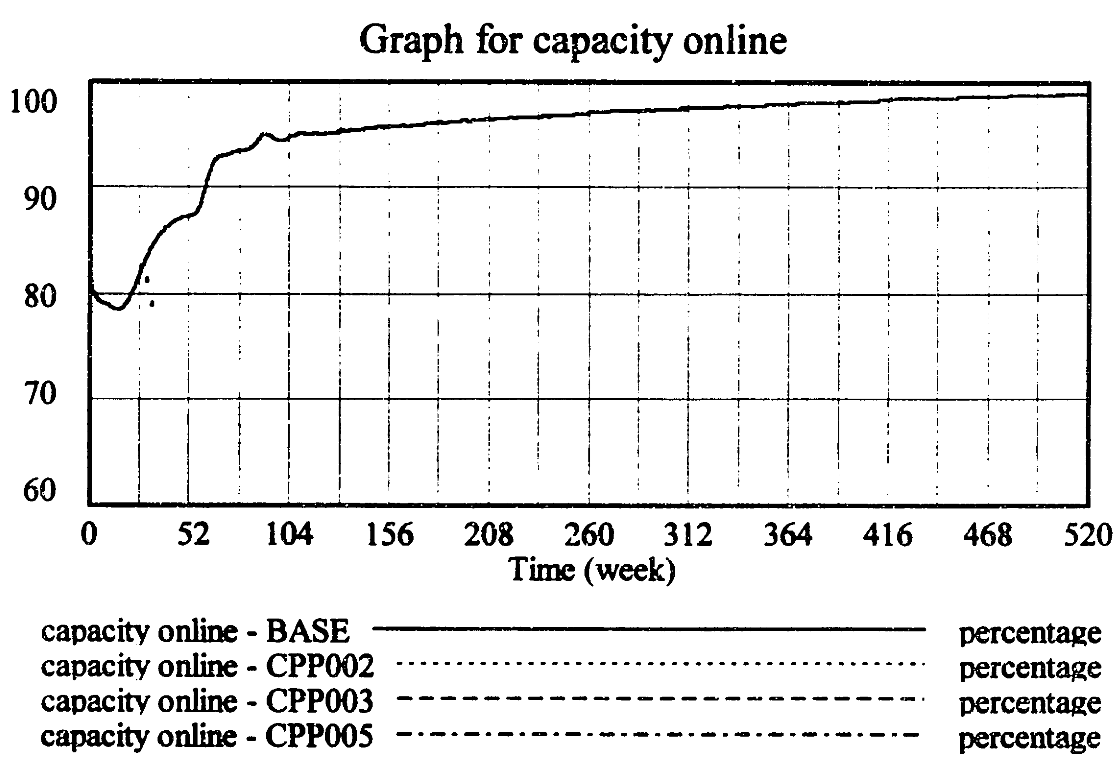
Variable 45



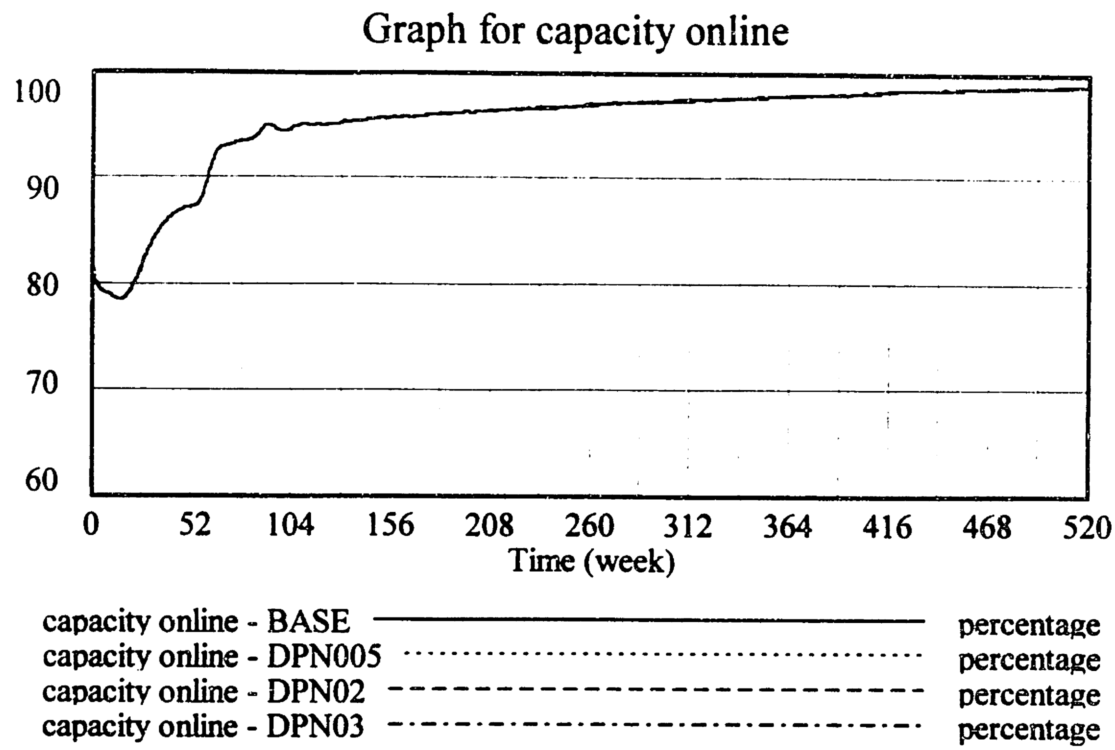
Variable 46



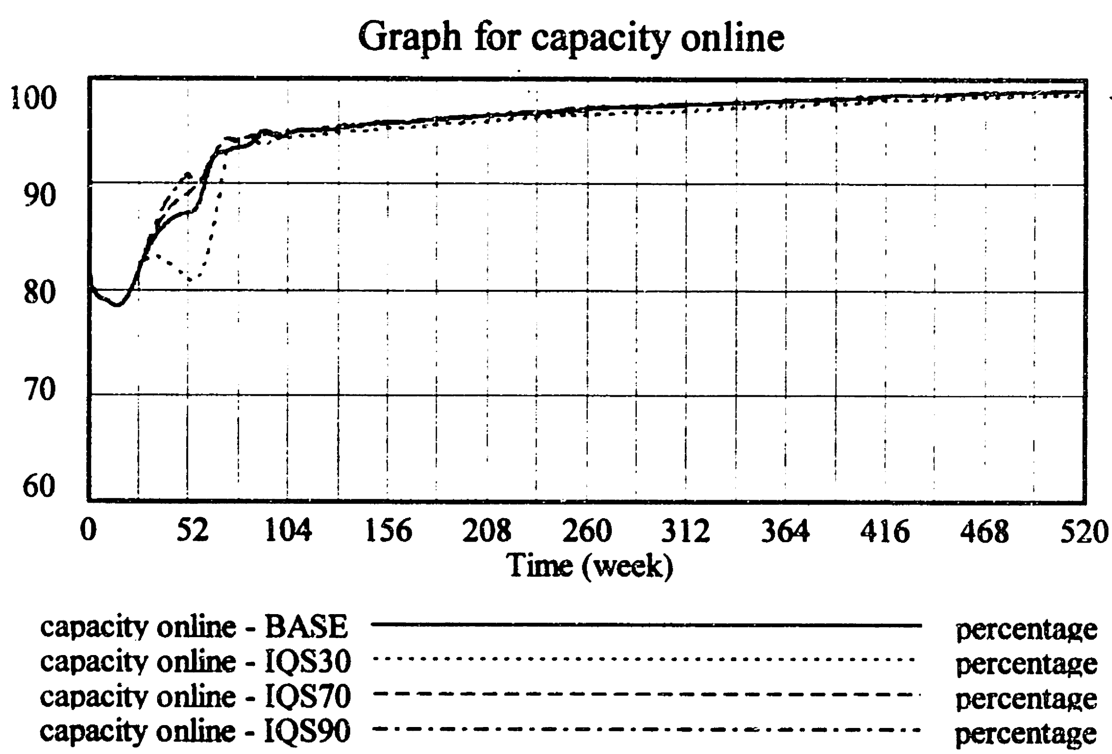
Variable 47



Variable 48

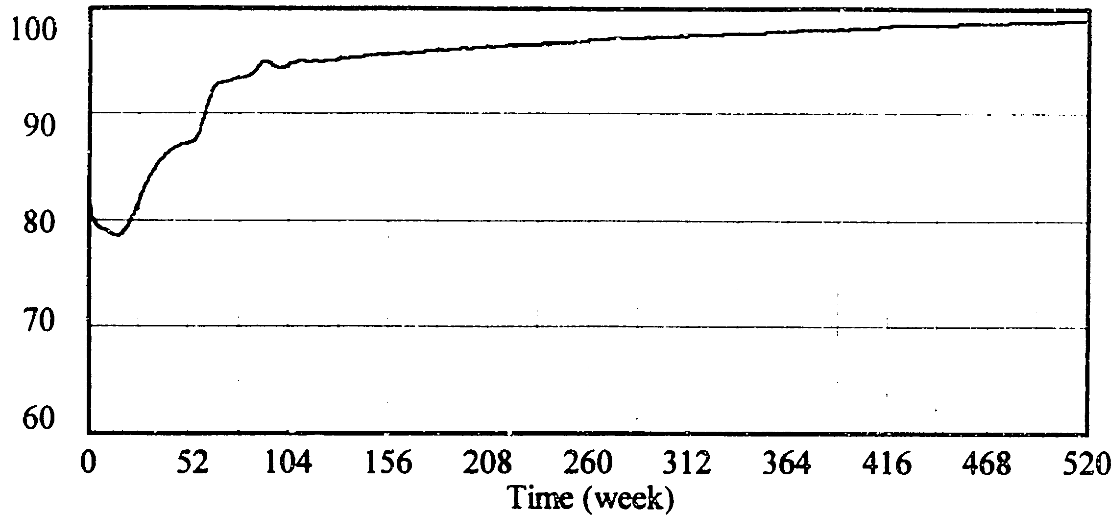


Variable 49



Variable 50

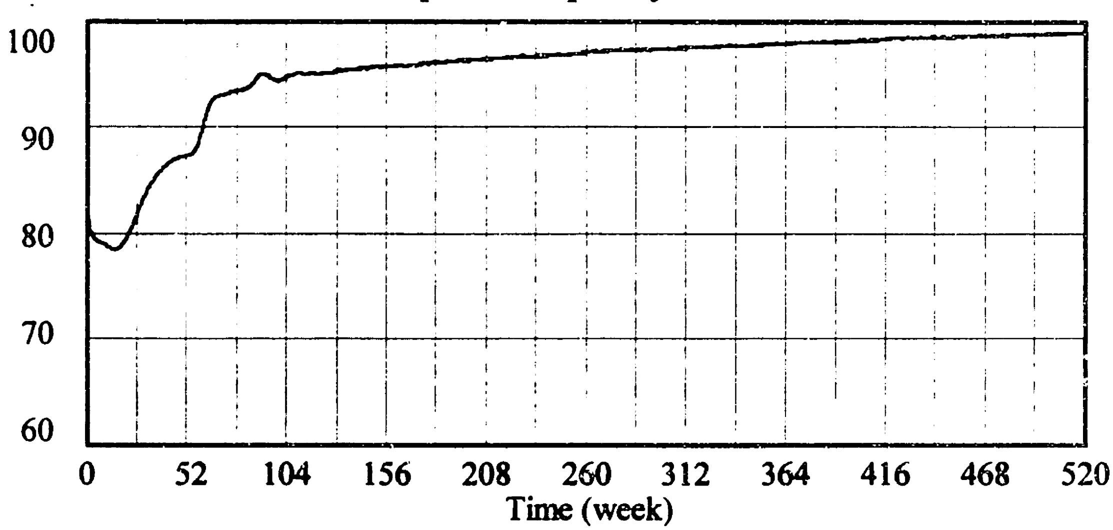
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - NPD3 ········ percentage
capacity online - NPD4 - - - - percentage
capacity online - NPD8 -·-·-·- percentage

Variable 51

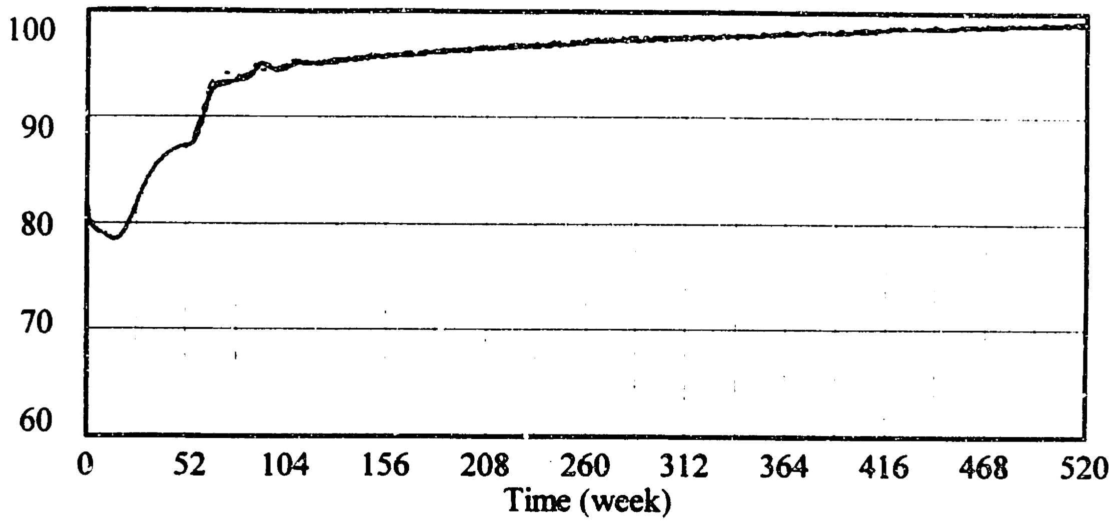
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - SPU01 ········ percentage
capacity online - SPU03 - - - - percentage
capacity online - SPU05 -·-·-·- percentage

Variable 52

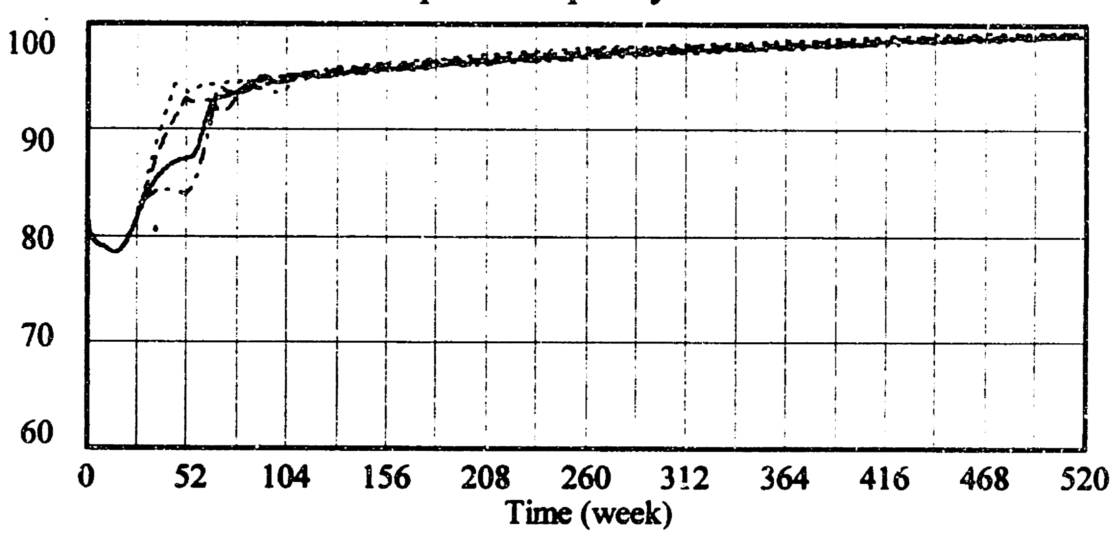
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - DPP4 ········· percentage
capacity online - DPP45 - - - - - percentage
capacity online - DPP5 -·-·-·-· percentage

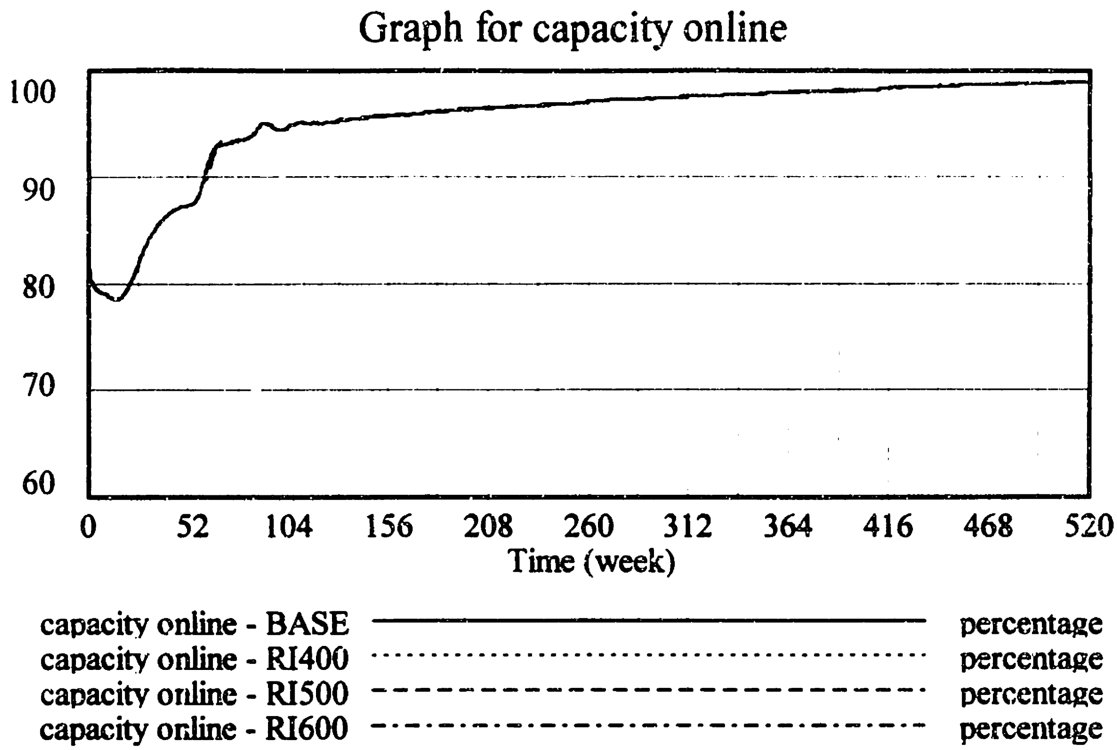
Variable 53

Graph for capacity online

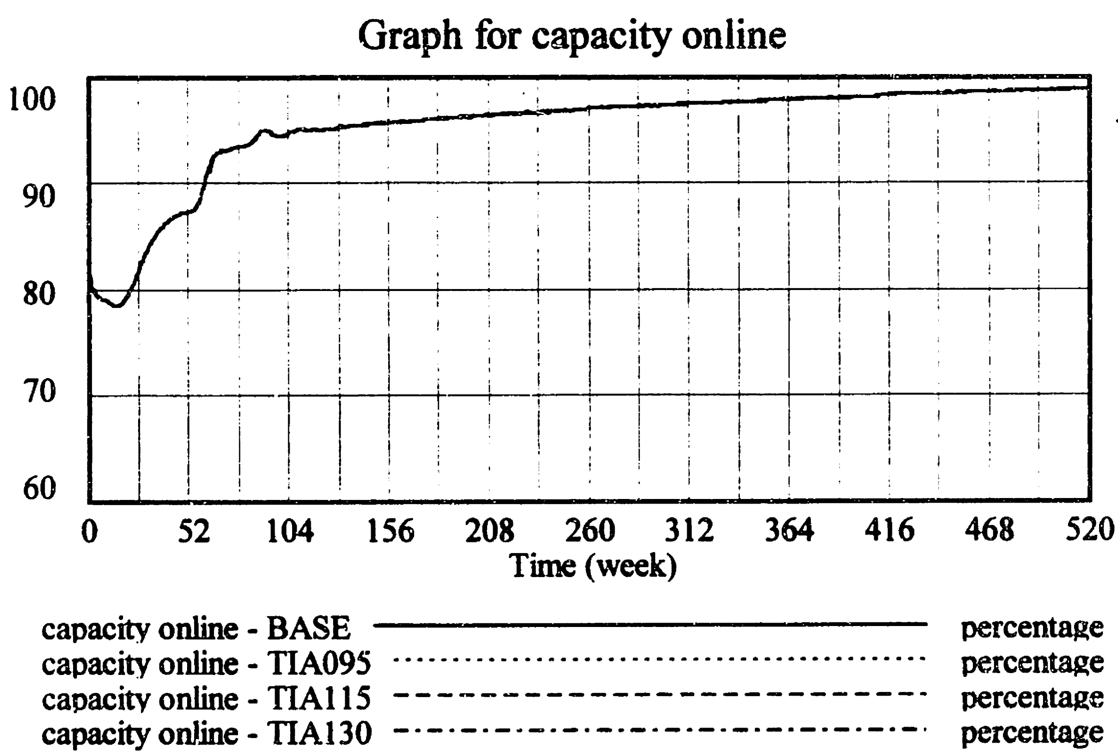


capacity online - BASE ——— percentage
capacity online - APP3 ········· percentage
capacity online - APP4 - - - - - percentage
capacity online - APP55 -·-·-·-· percentage

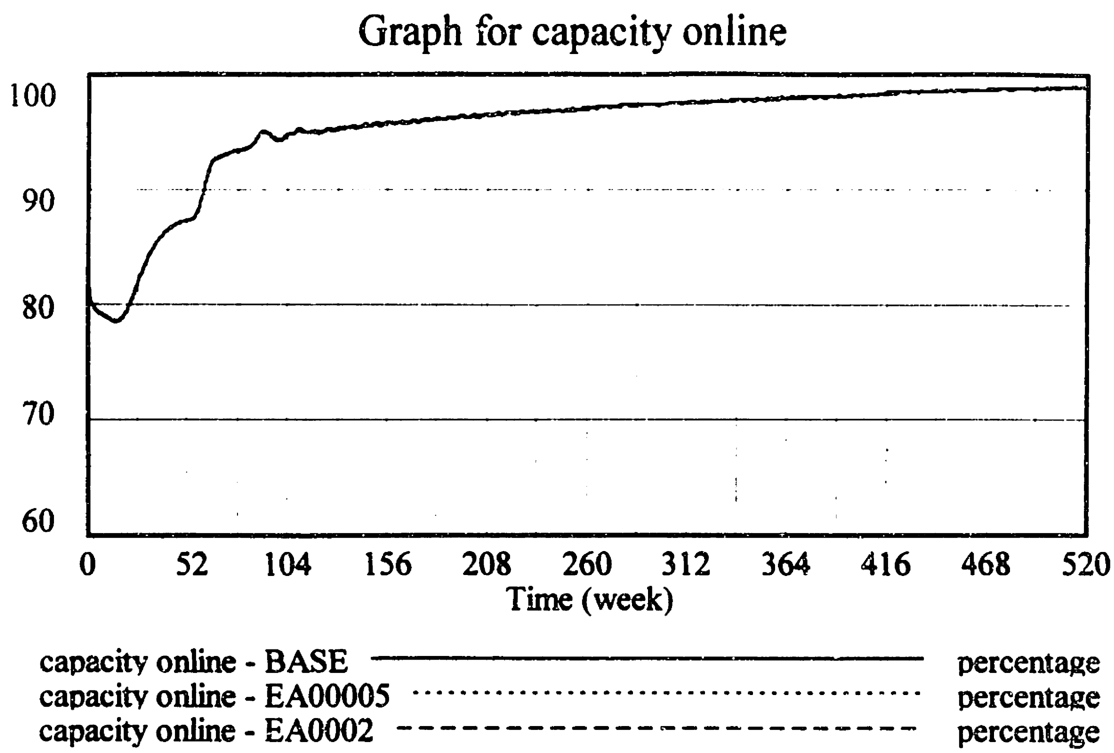
Variable 54



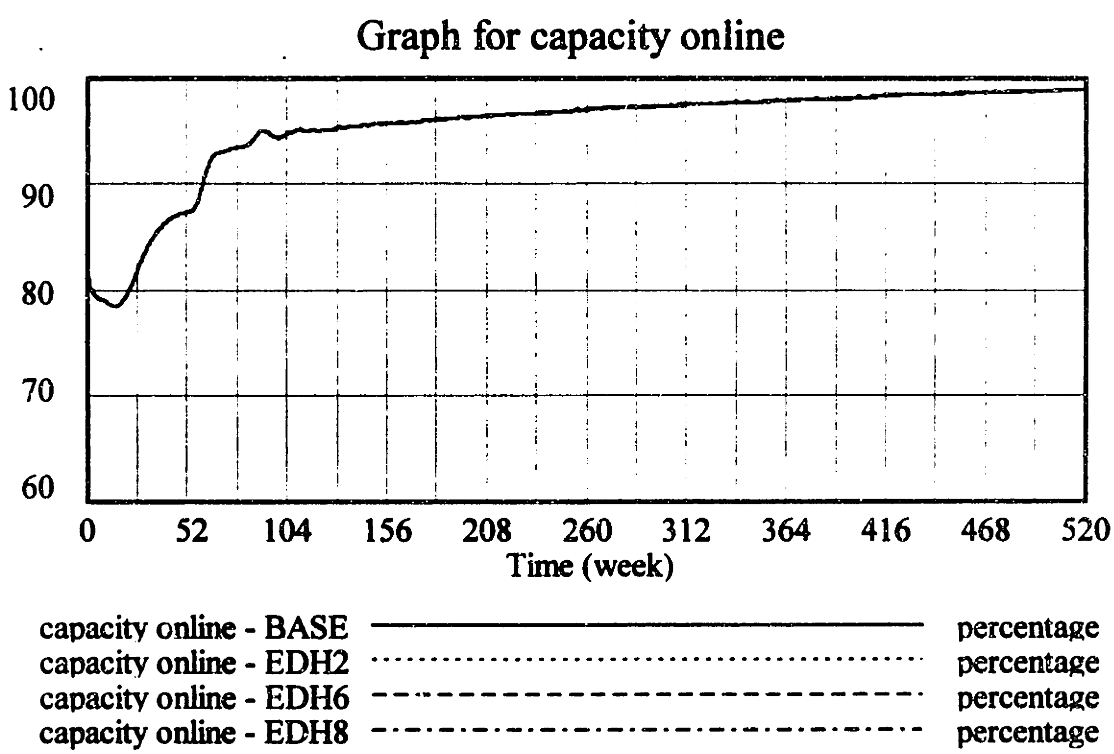
Variable 55



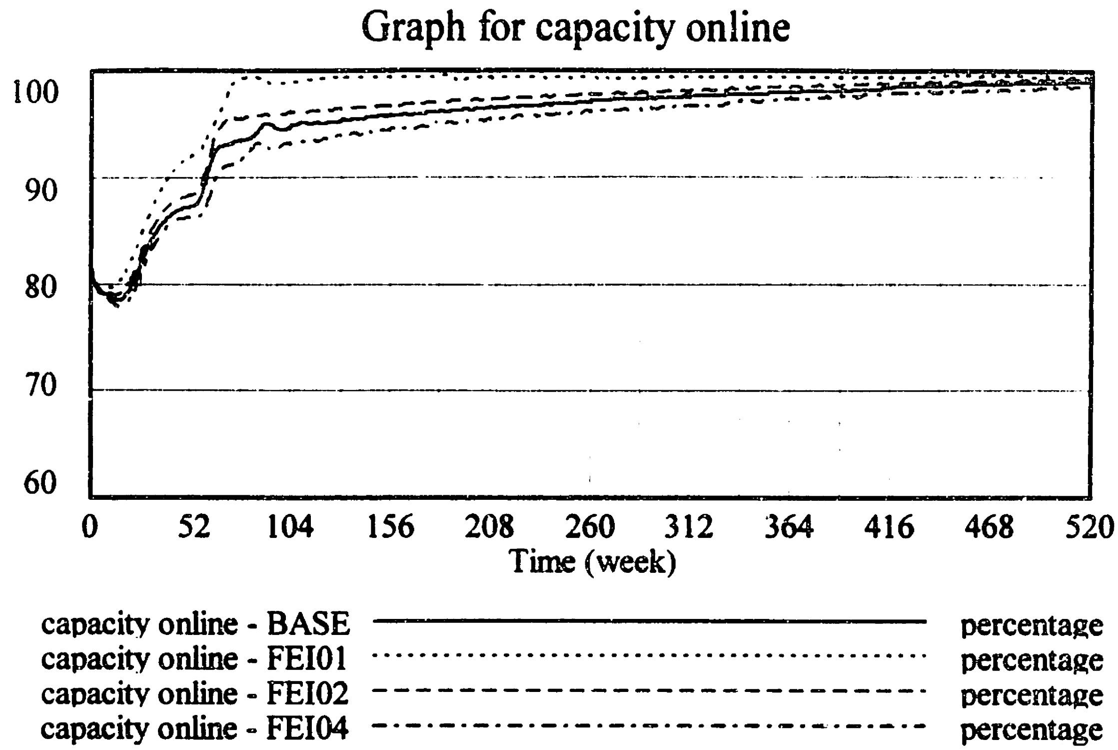
Variable 56



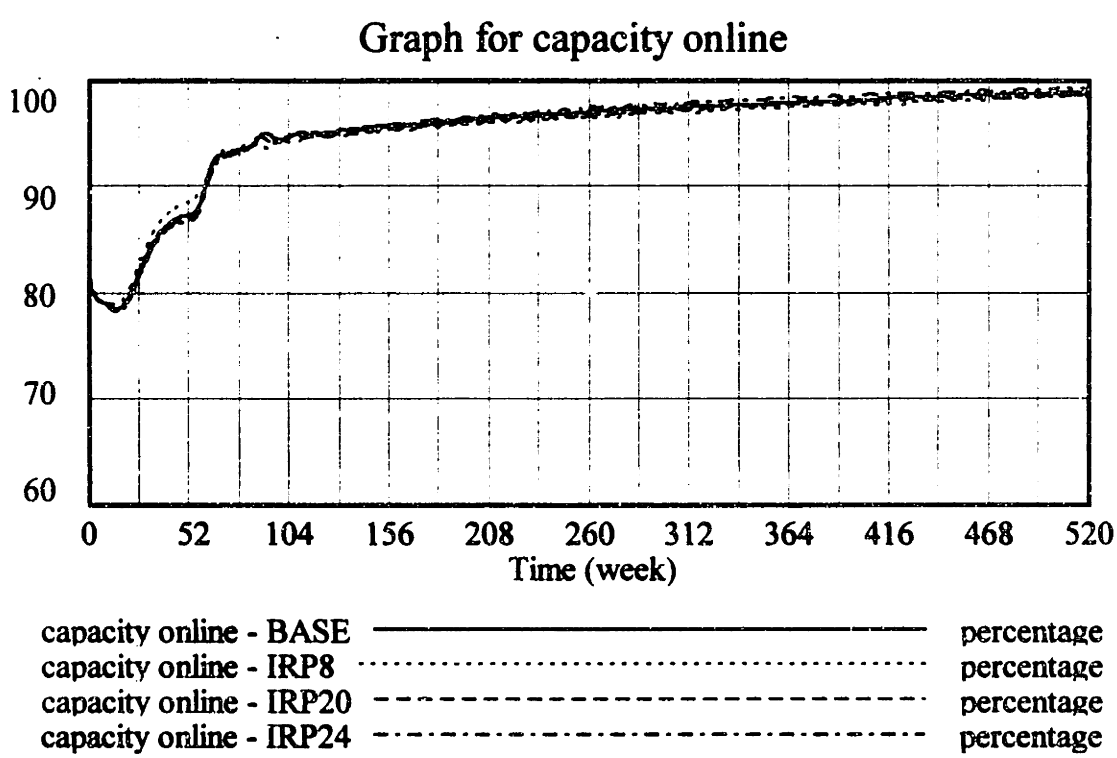
Variable 57



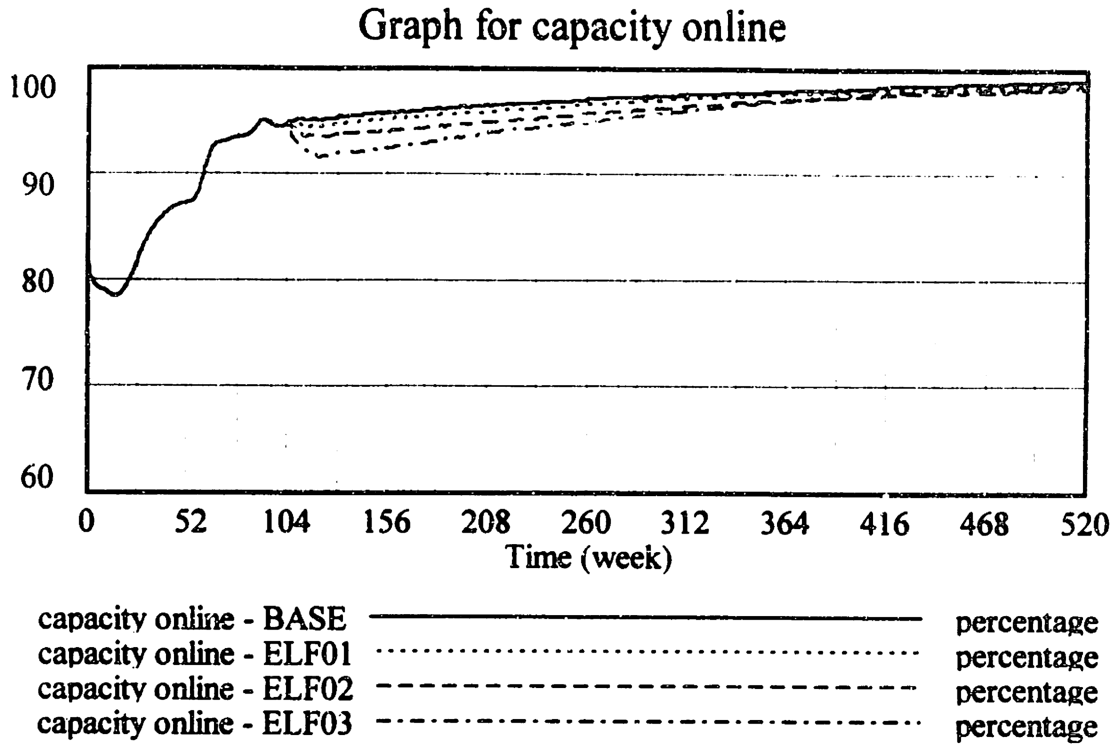
Variable 58



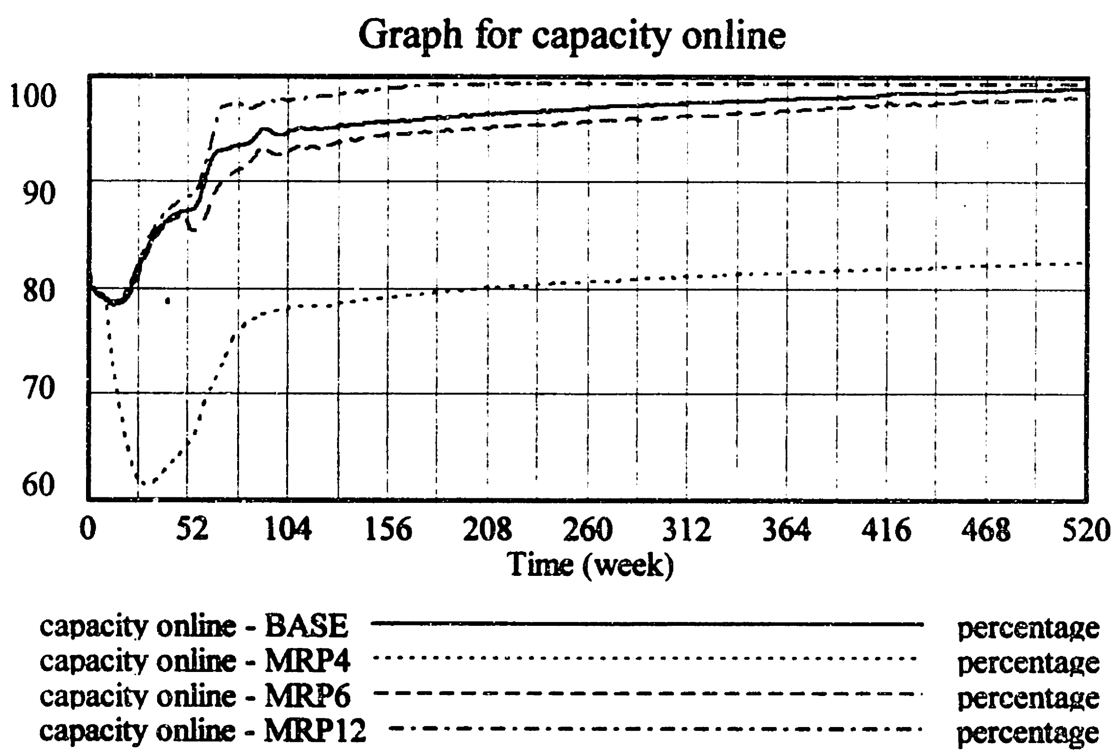
Variable 59



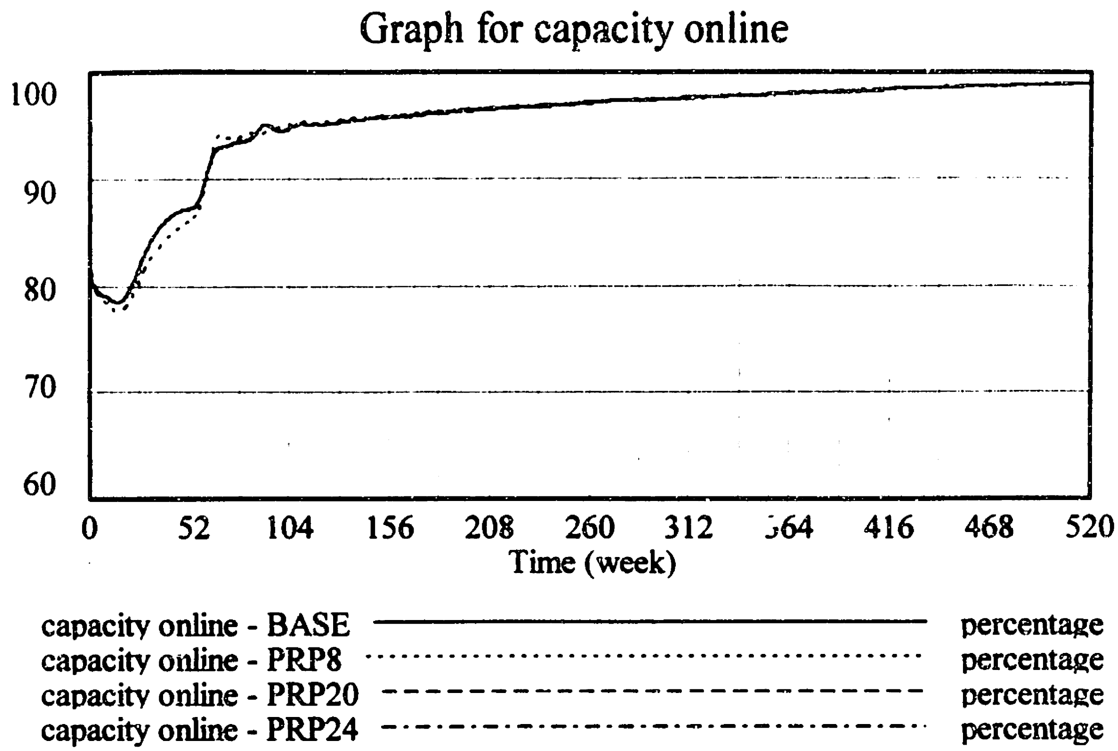
Variable 60



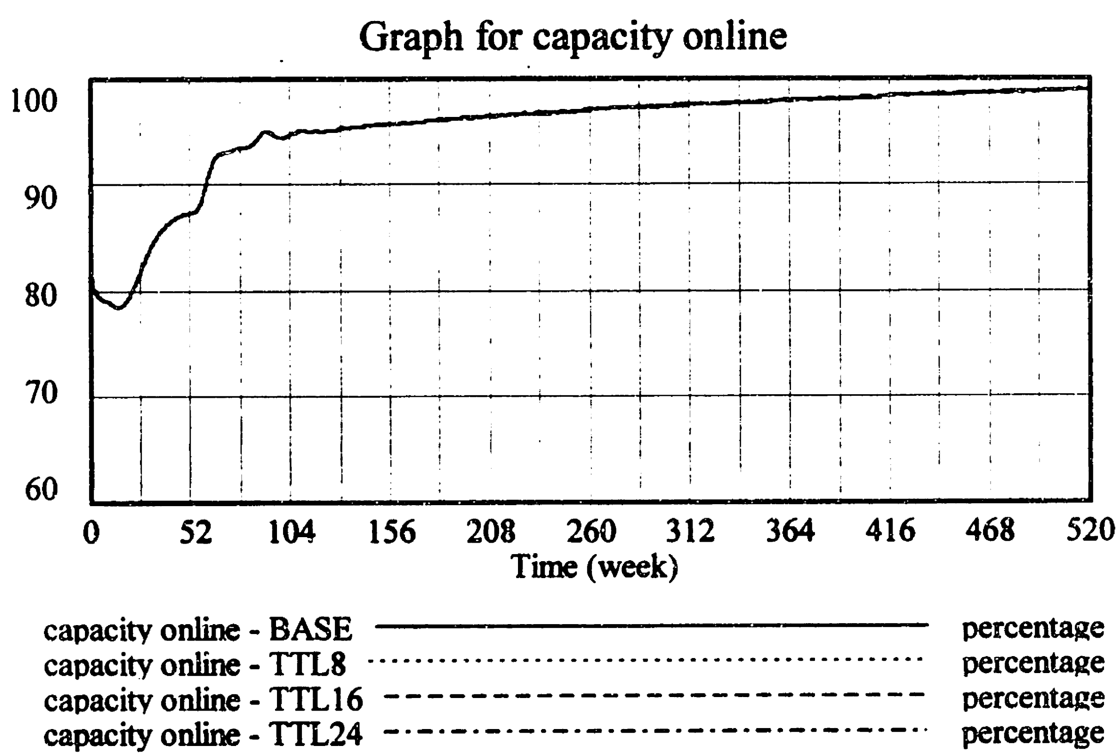
Variable 61



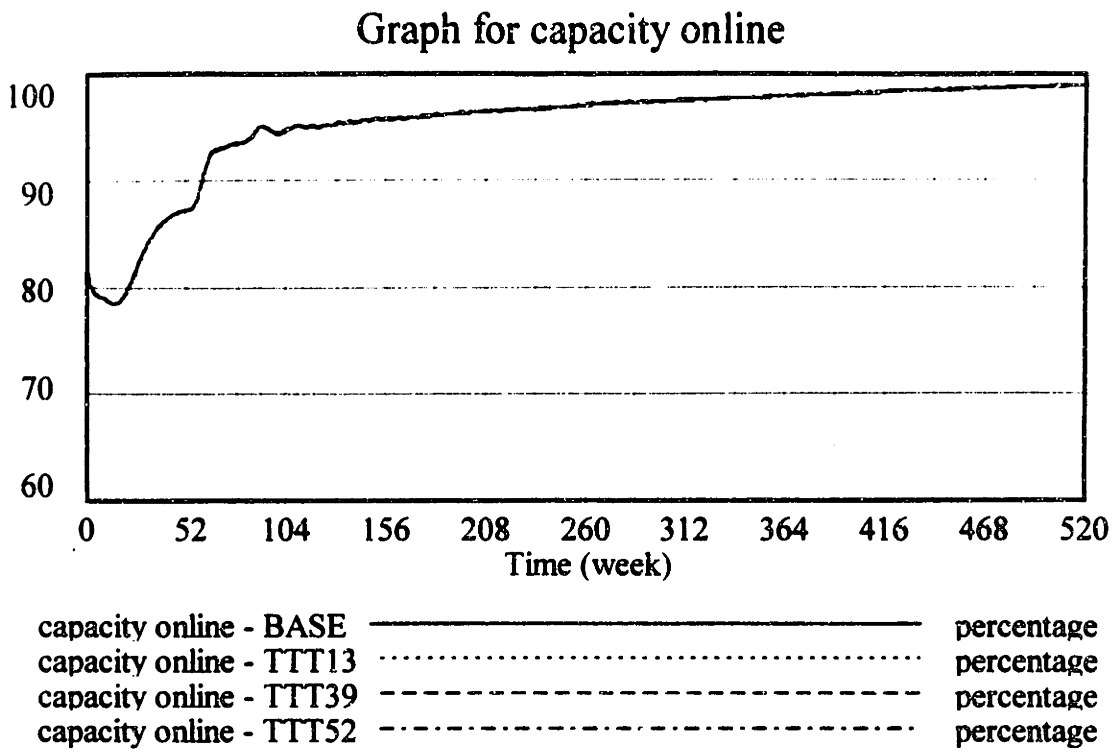
Variable 62



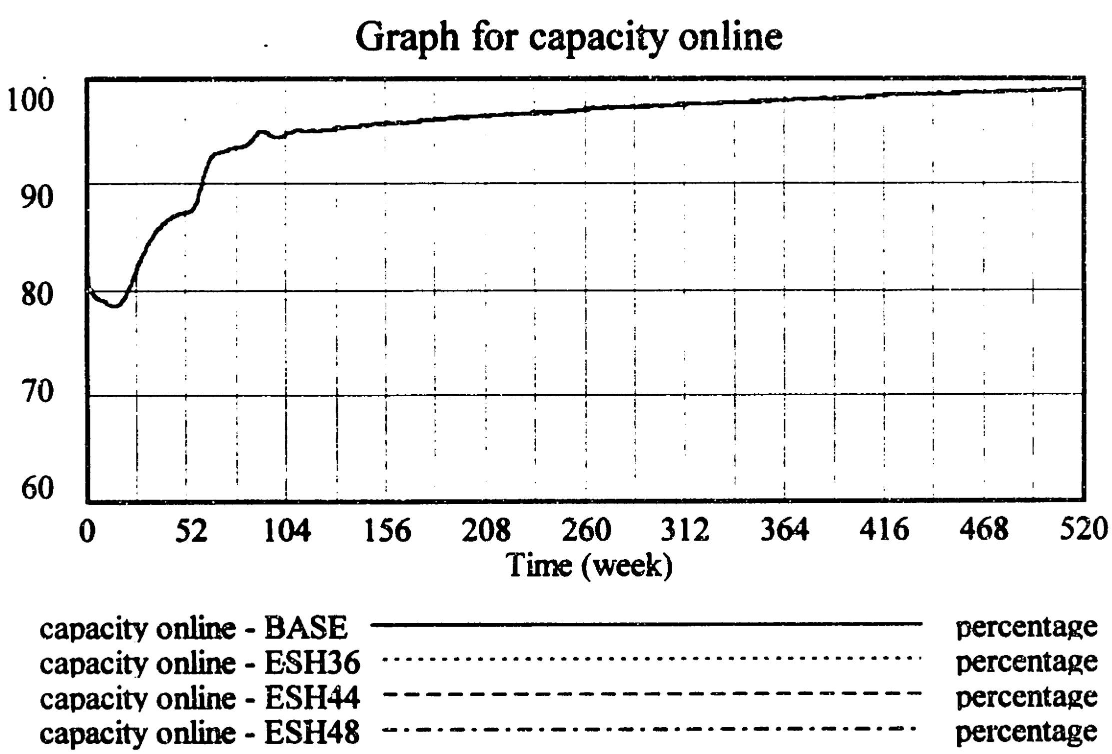
Variable 63



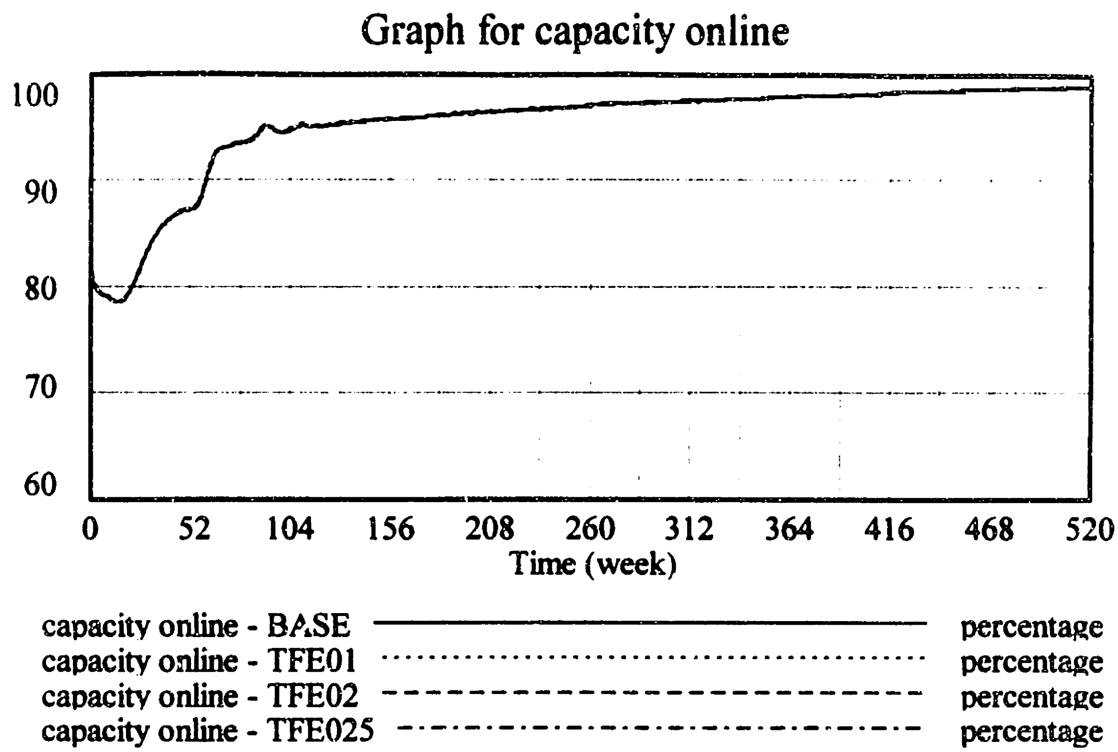
Variable 65



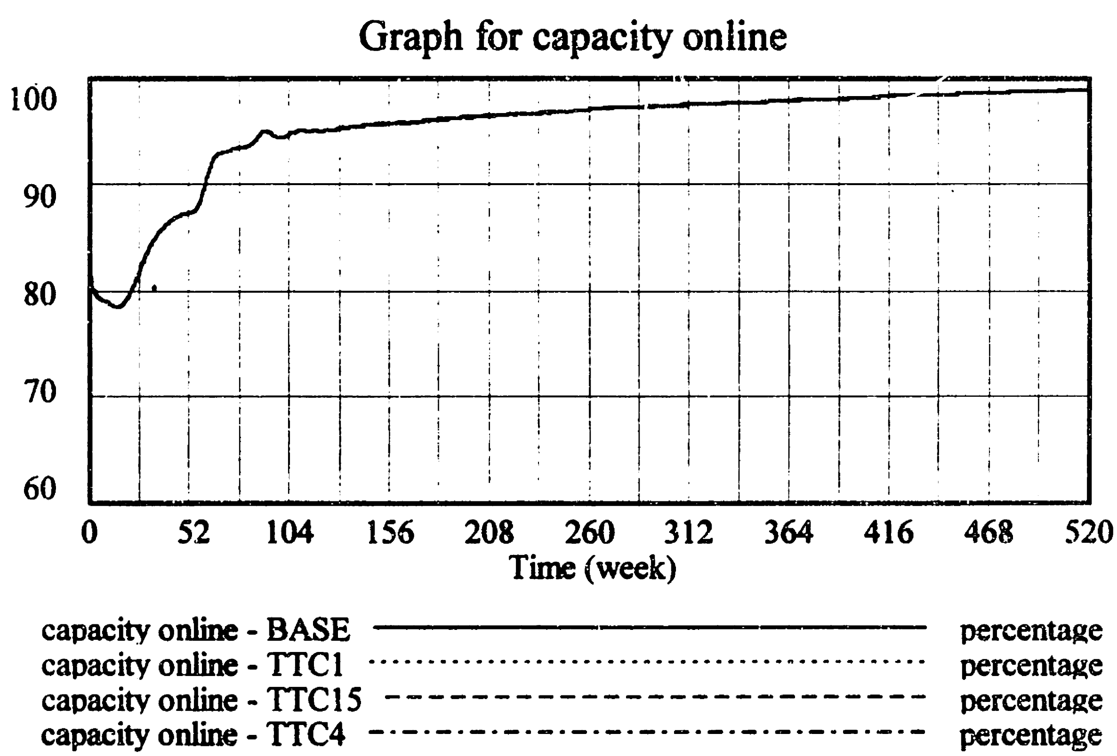
Variable 66



Variable 67

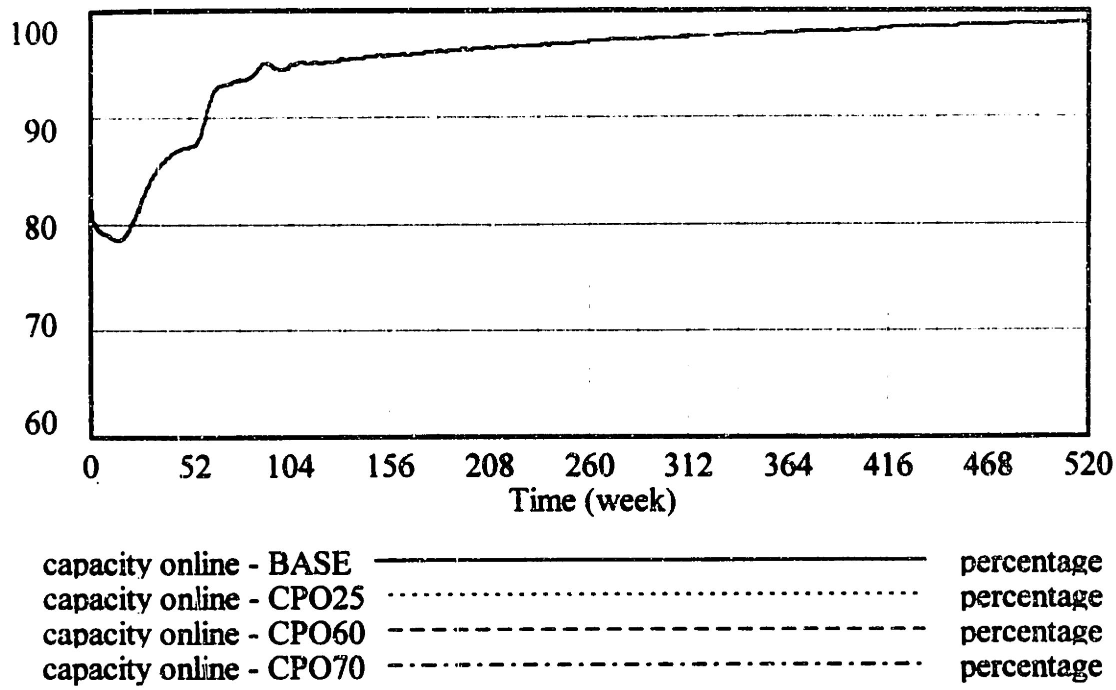


Variable 68



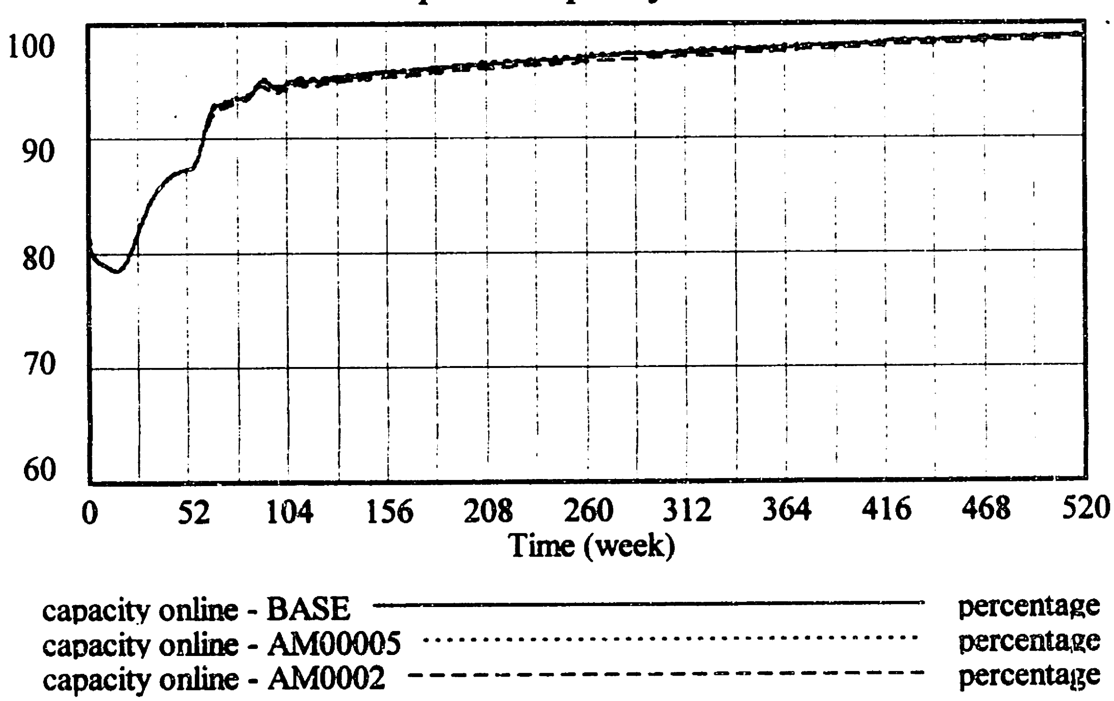
Variable 69

Graph for capacity online

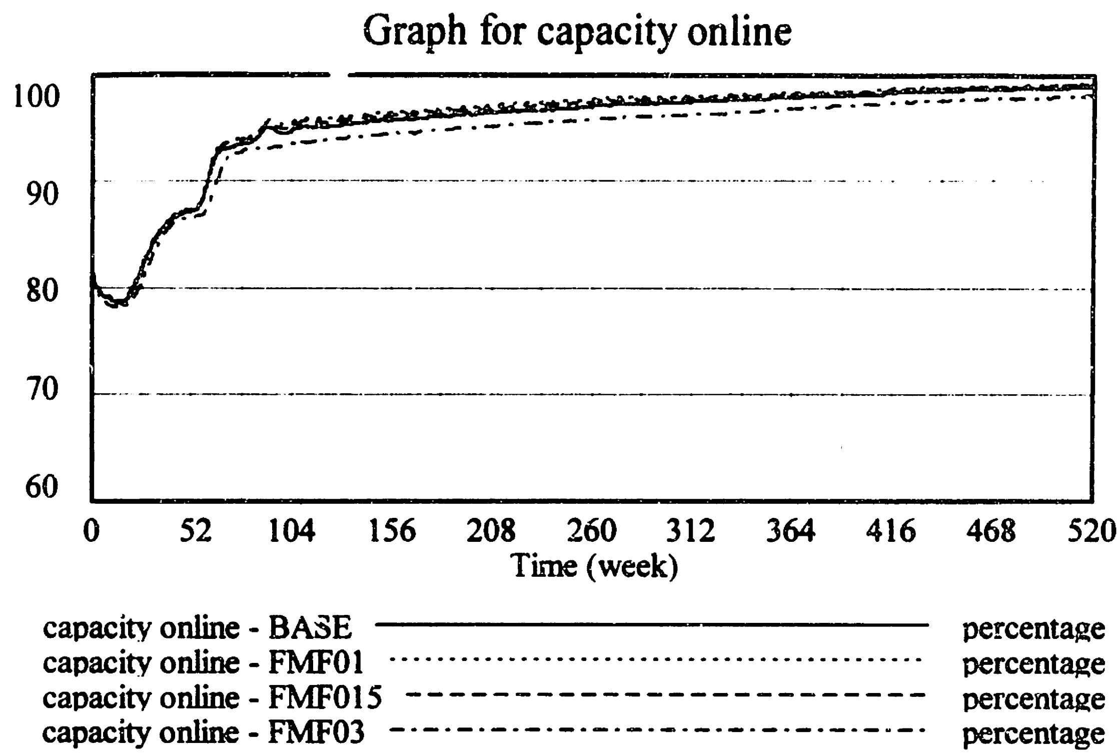


Variable 70

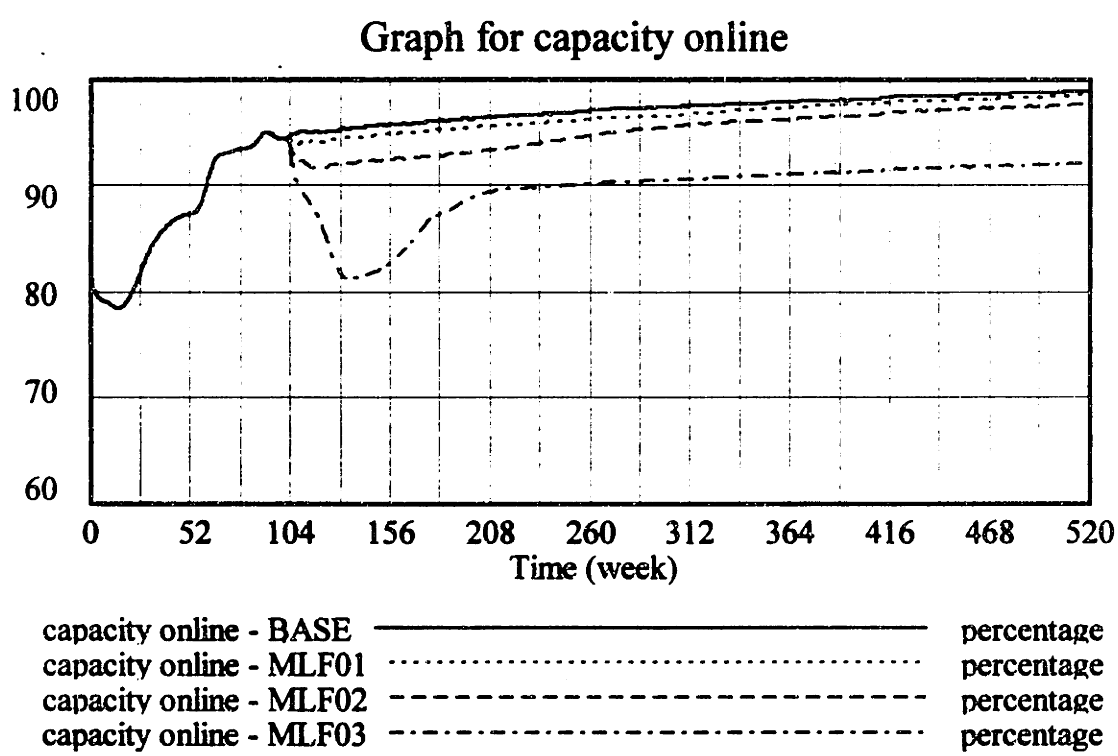
Graph for capacity online



Variable 71

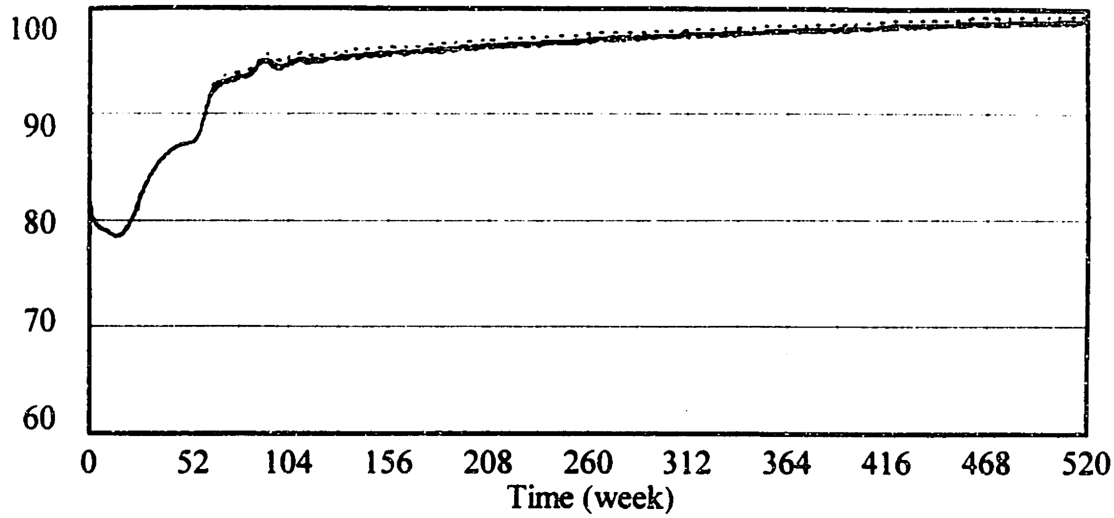


Variable 72



Variable 73

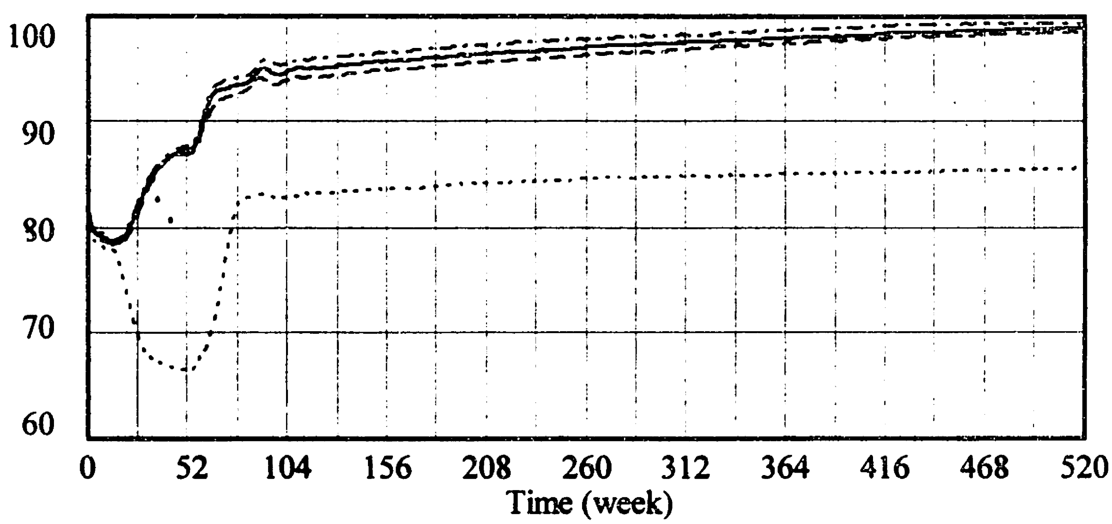
Graph for capacity online



capacity online - BASE ―――― percentage
capacity online - IRM6 ········ percentage
capacity online - IRM12 – – – – percentage
capacity online - IRM15 –·–·–· percentage

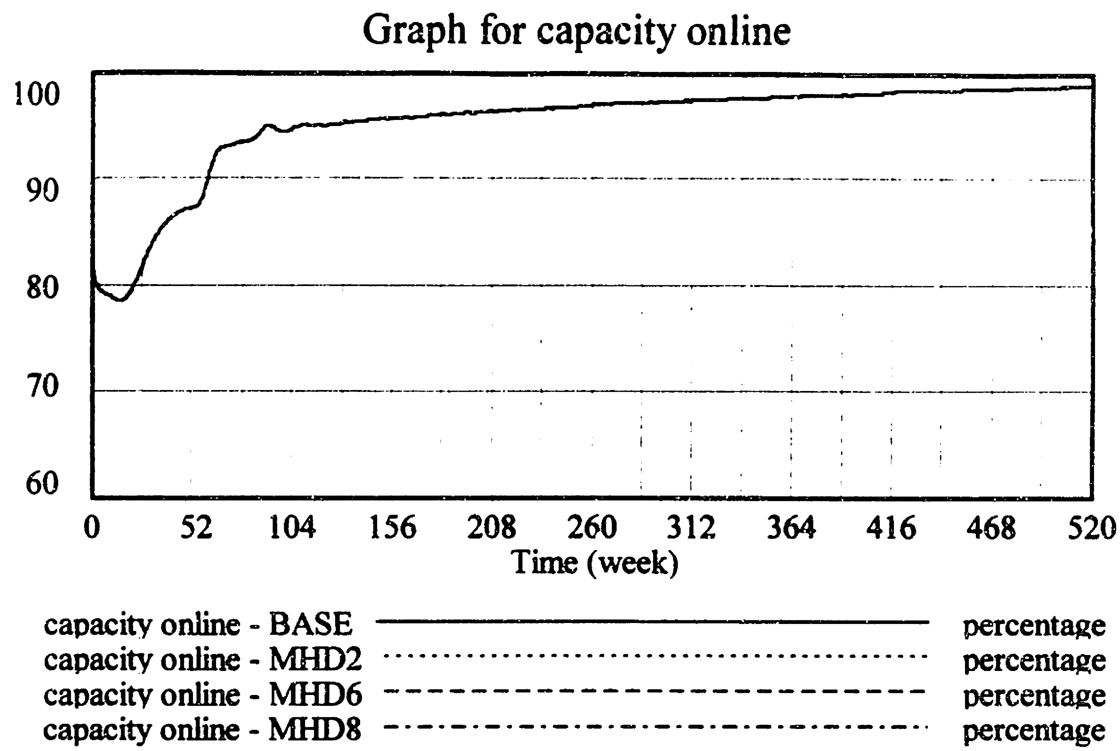
Variable 74

Graph for capacity online

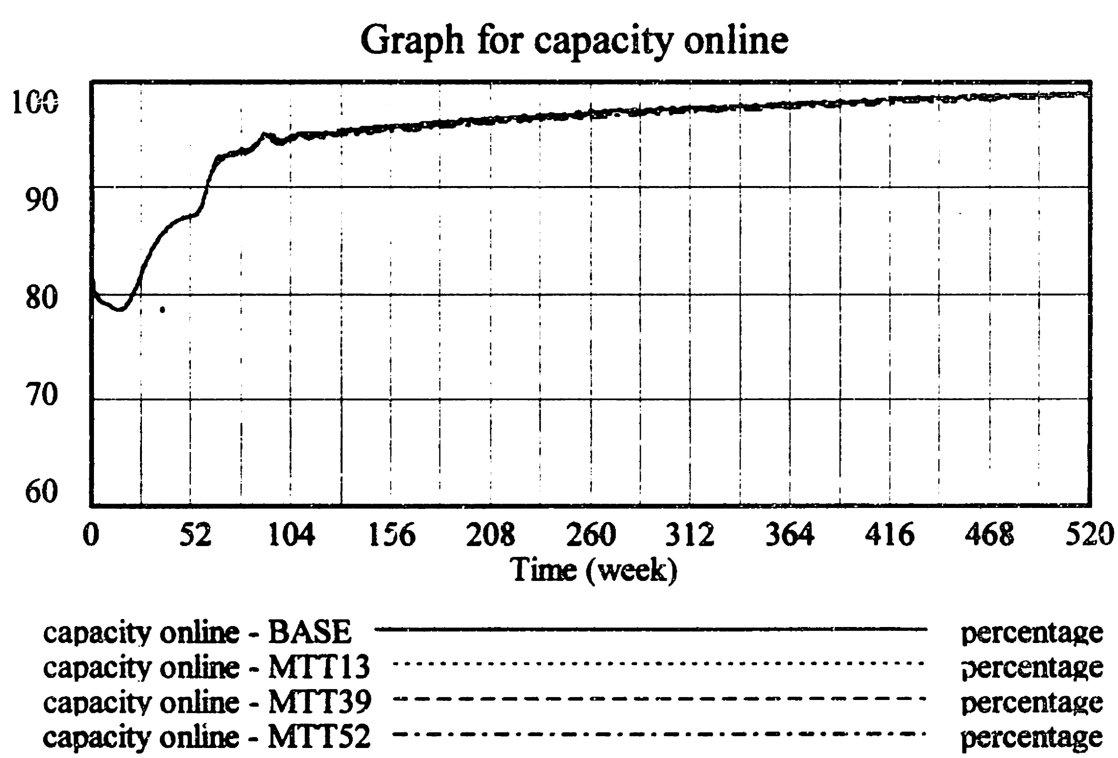


capacity online - BASE ―――― percentage
capacity online - MRM15 ········ percentage
capacity online - MRM18 – – – – percentage
capacity online - MRM25 –·–·–· percentage

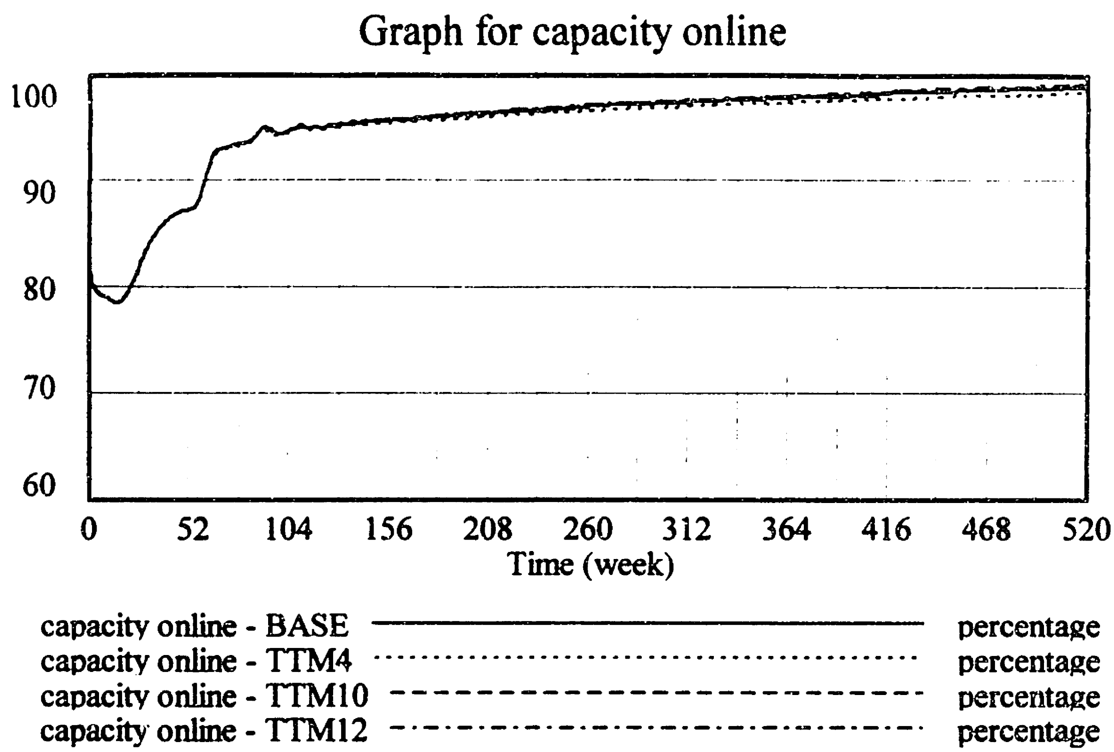
Variable 75



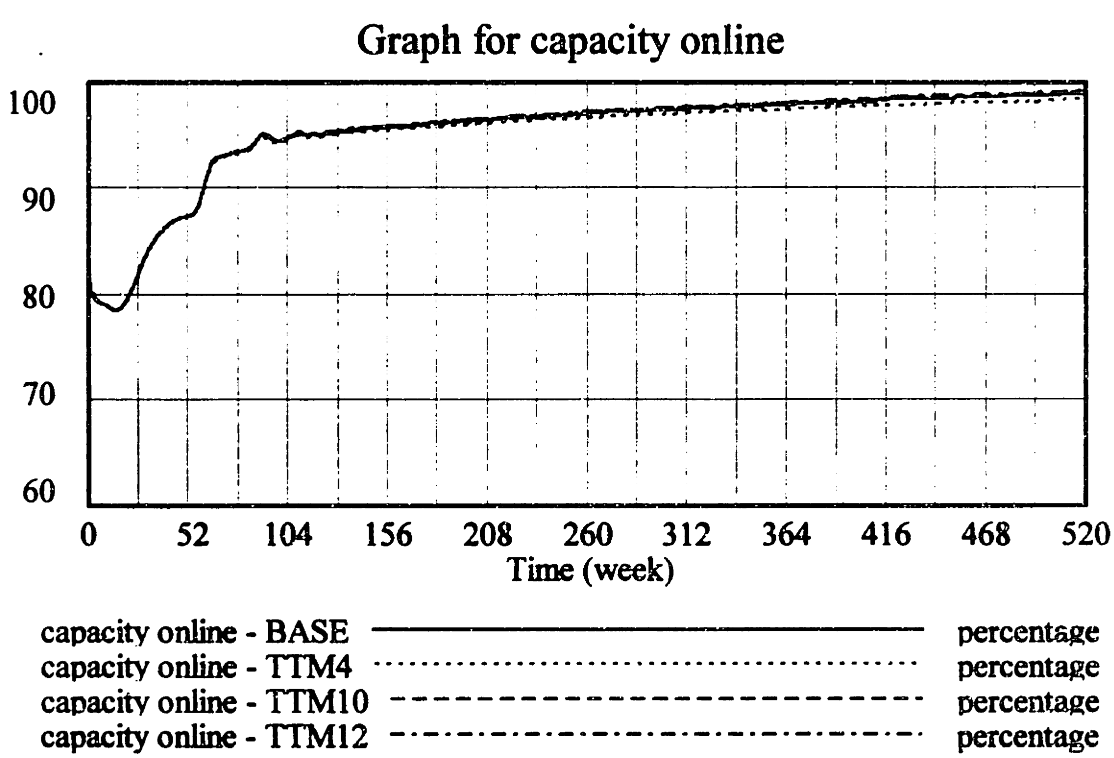
Variable 76



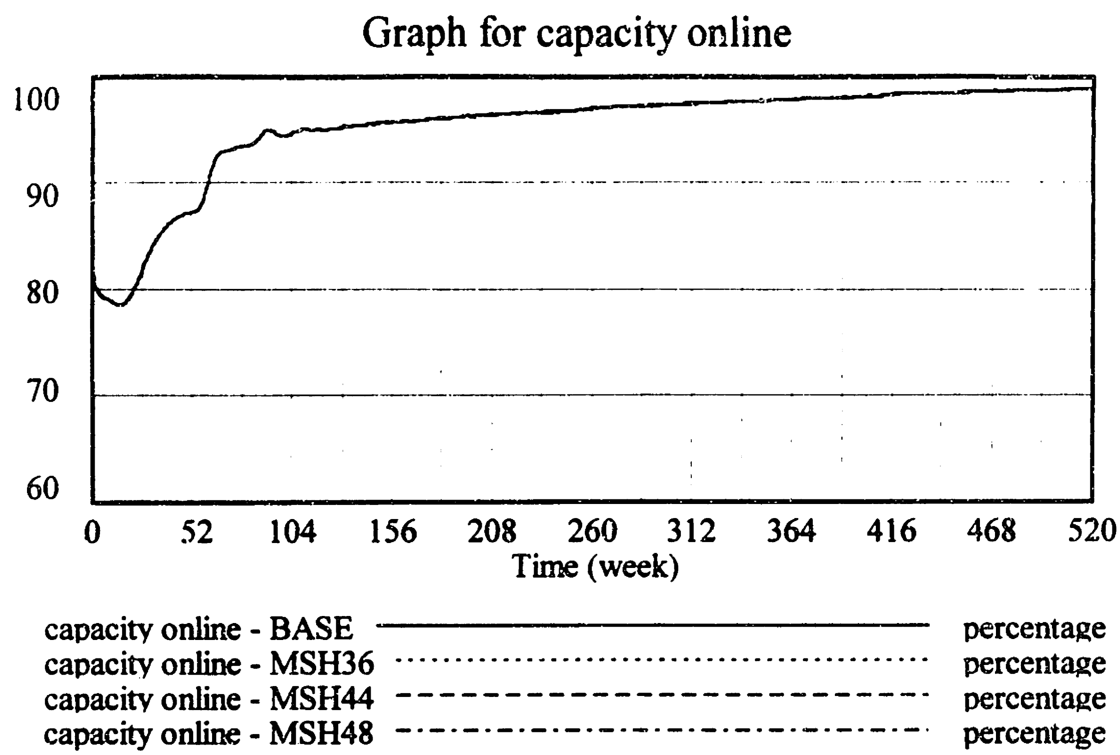
Variable 77



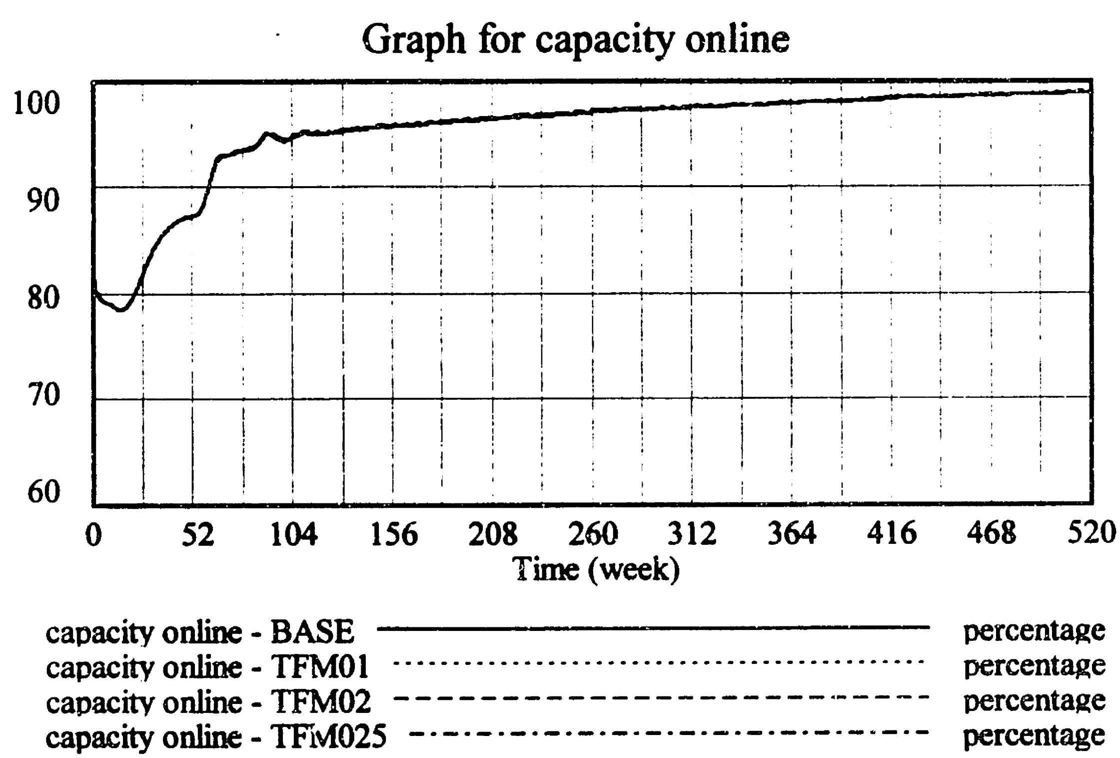
Variable 78



Variable 79

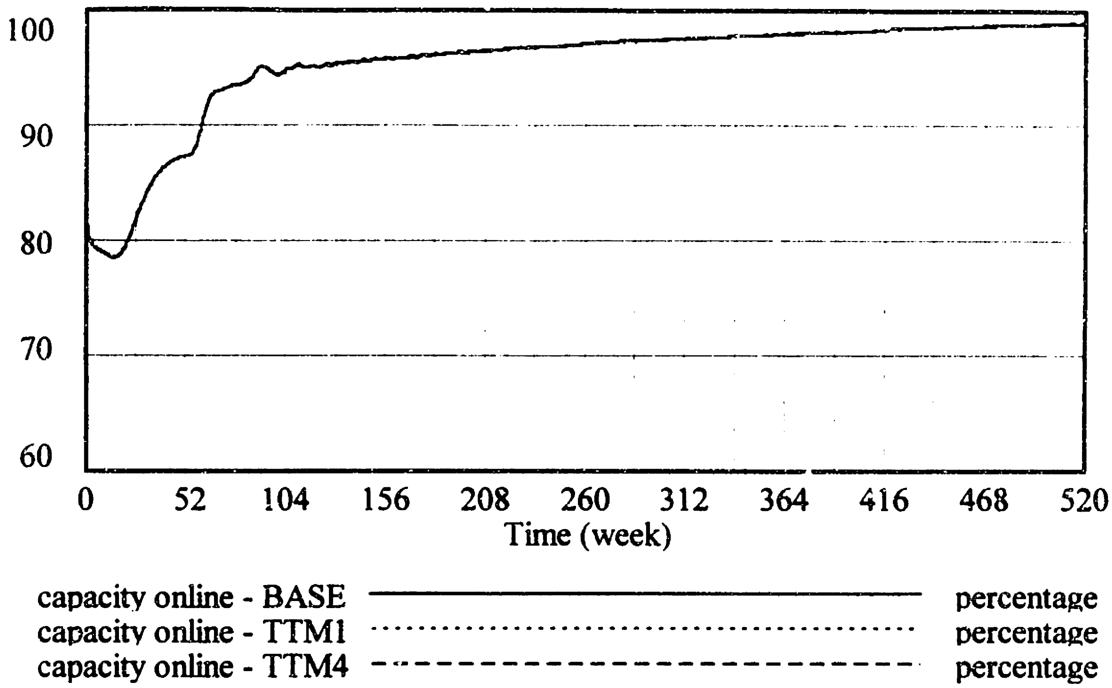


Variable 80



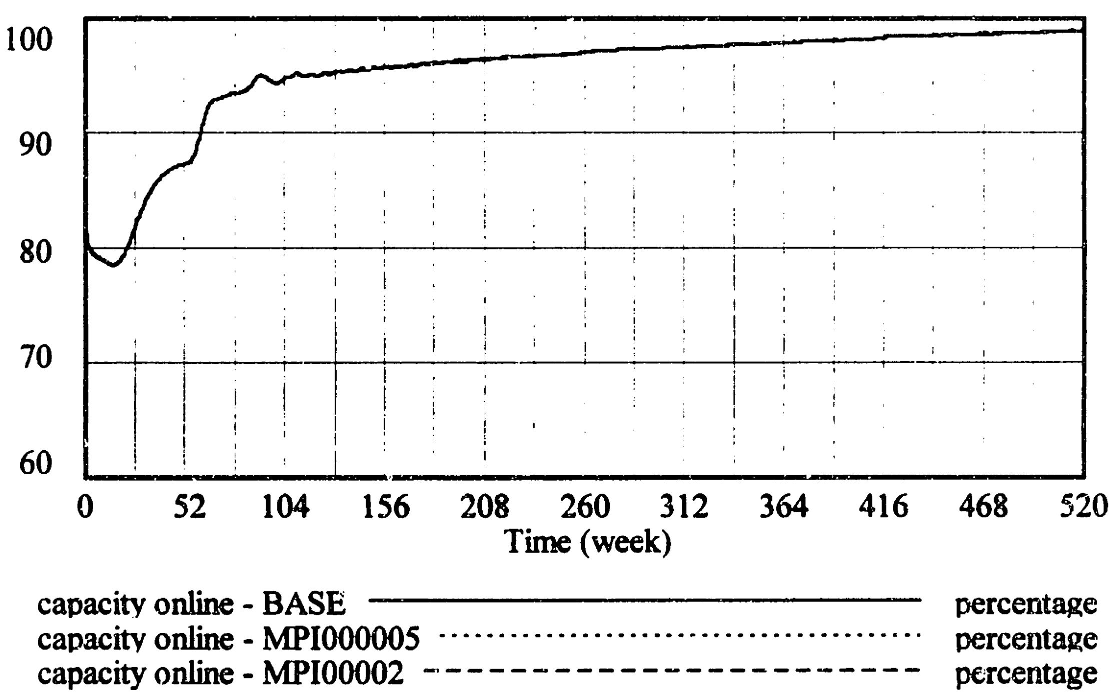
Variable 81

Graph for capacity online



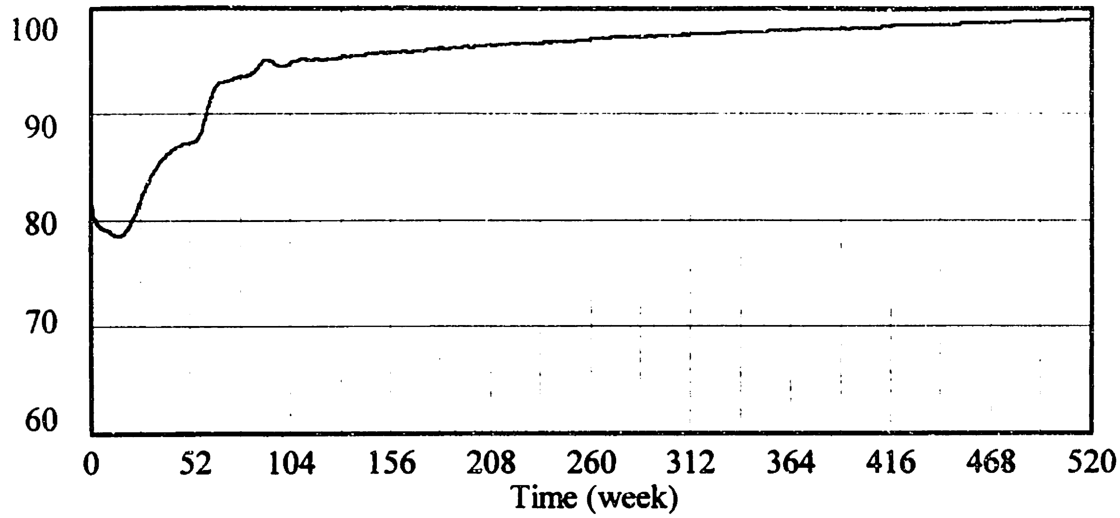
Variable 82

Graph for capacity online



Variable 83

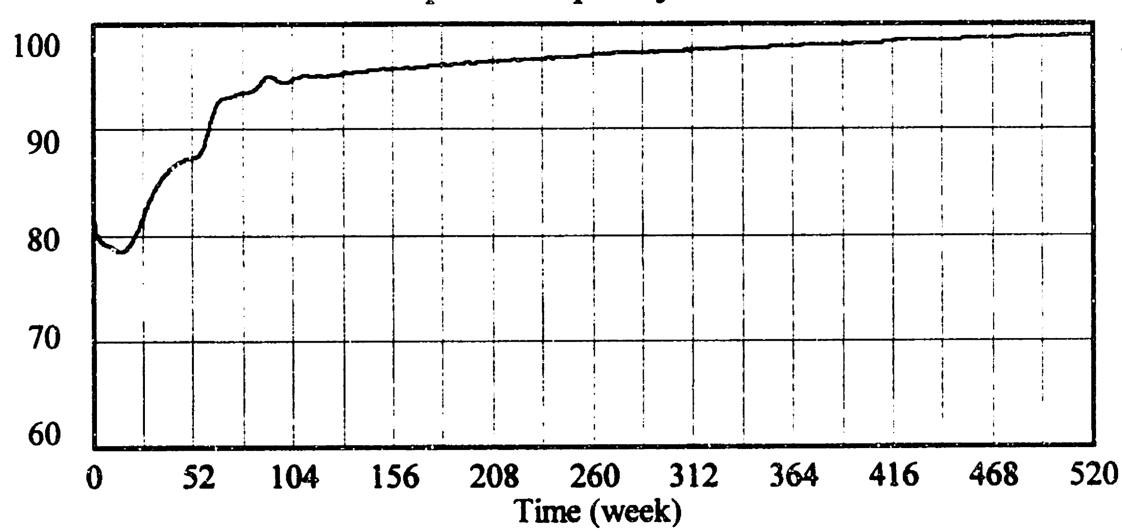
Graph for capacity online



capacity online - BASE percentage
capacity online - MPF005 percentage
capacity online - MPF015 percentage
capacity online - MPF02 percentage

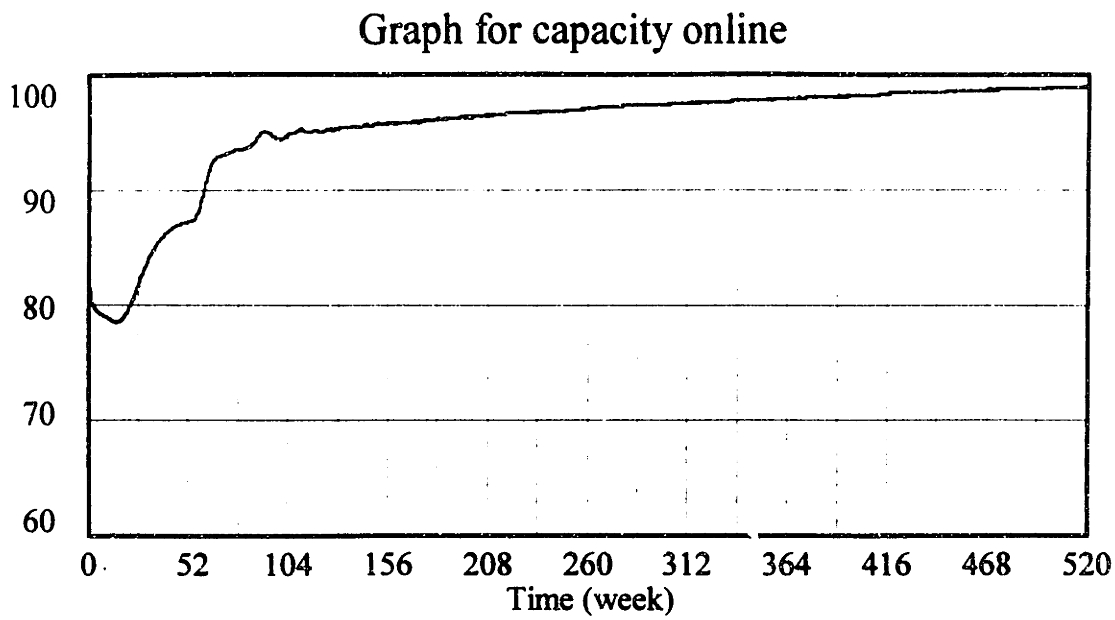
Variable 84

Graph for capacity online



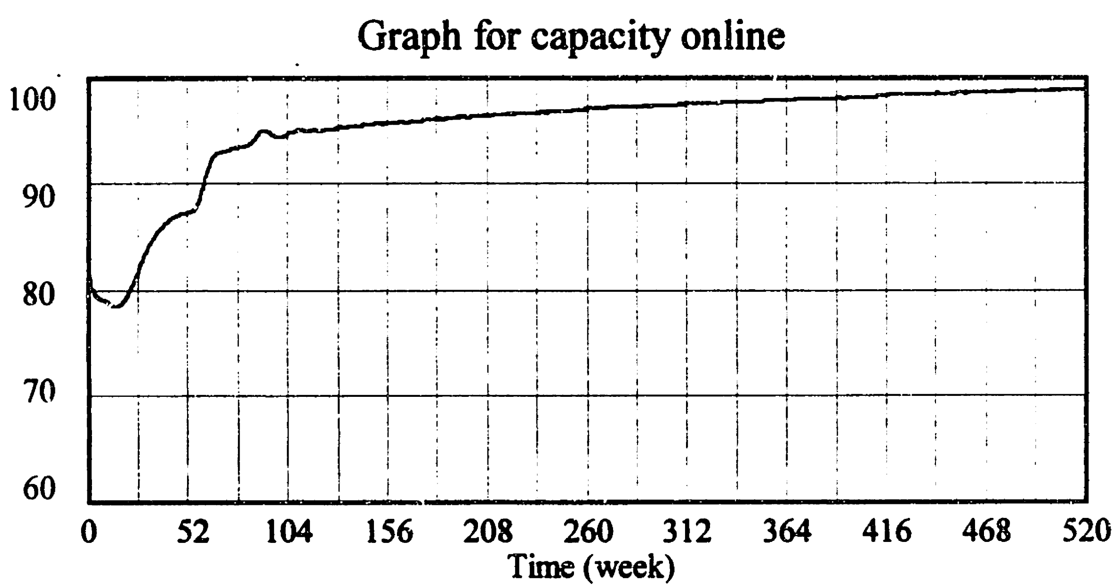
capacity online - BASE percentage
capacity online - MPF005 percentage
capacity online - MPF015 percentage
capacity online - MPF02 percentage

Variable 85



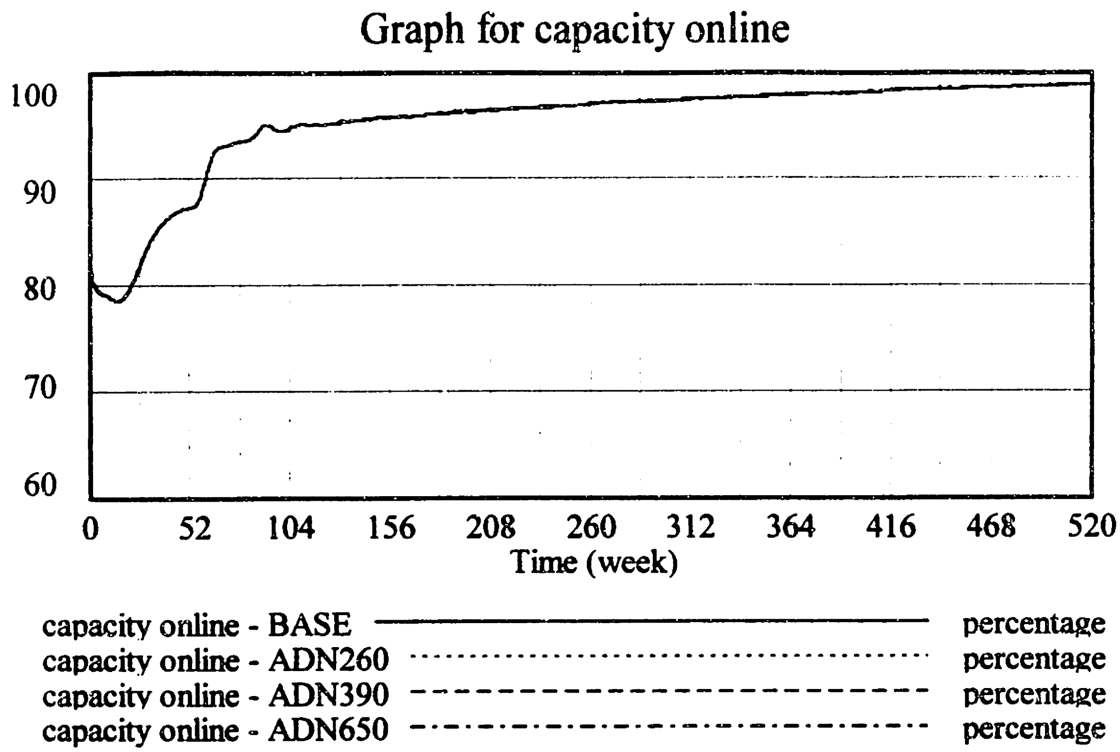
capacity online - BASE ———————————— percentage
capacity online - MPU00005 ·················· percentage
capacity online - MPU0002 - - - - - - - - - - - - percentage

Variable 86

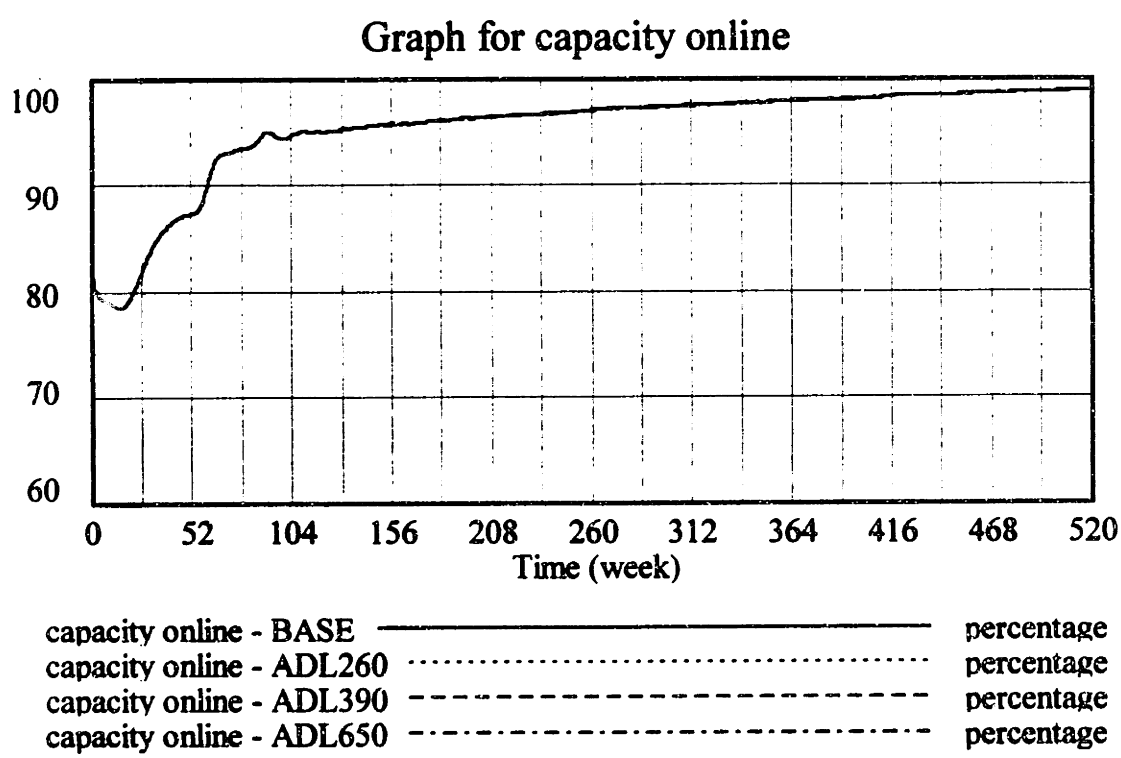


capacity online - BASE ———————————— percentage
capacity online - MPW00002 ·················· percentage
capacity online - MPW0001 - - - - - - - - - - - - percentage
capacity online - MPW0002 -·-·-·-·-·-·-·-·-·- percentage

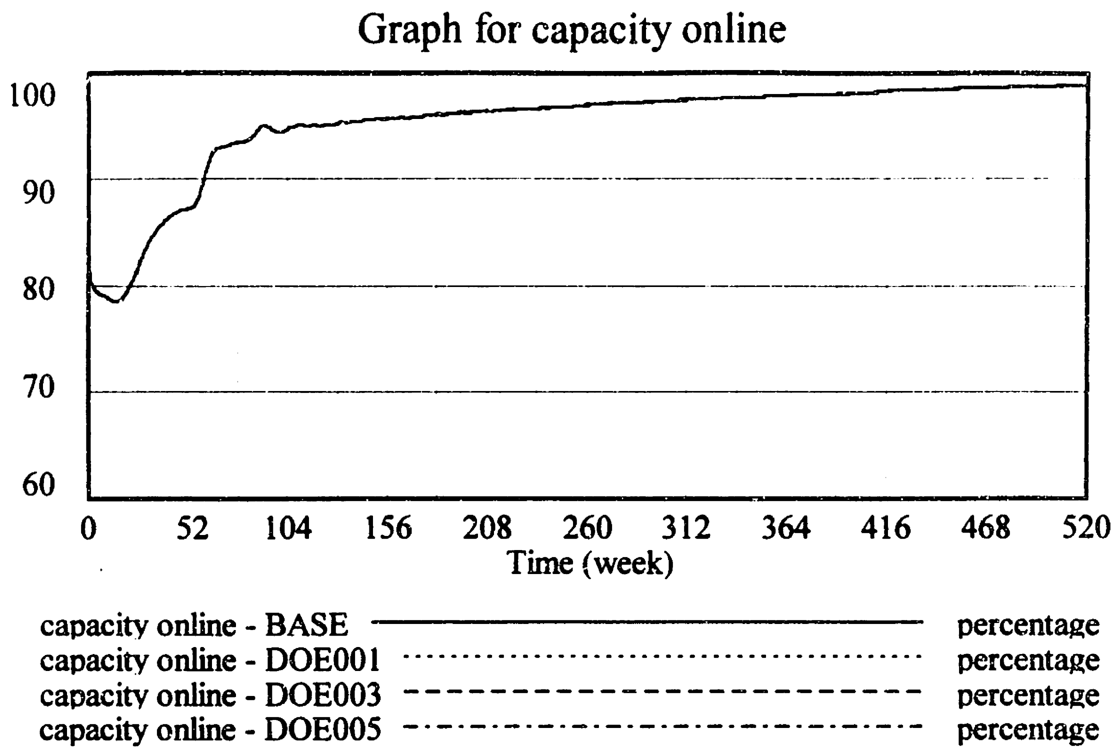
Variable 87



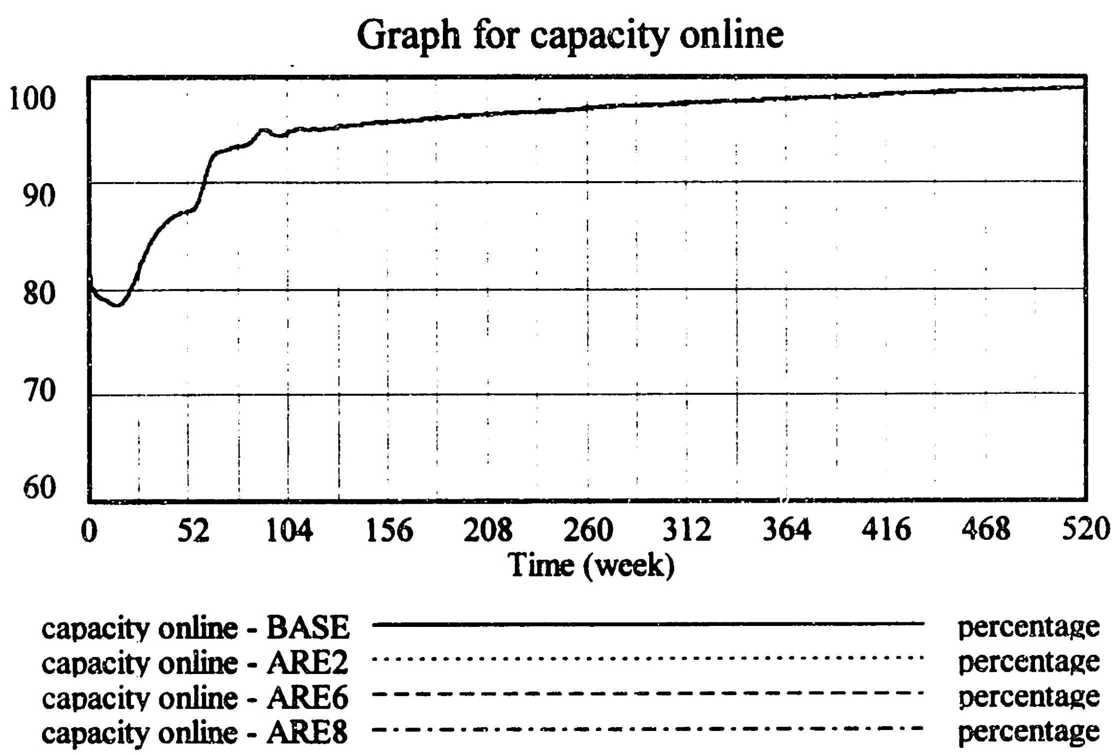
Variable 88



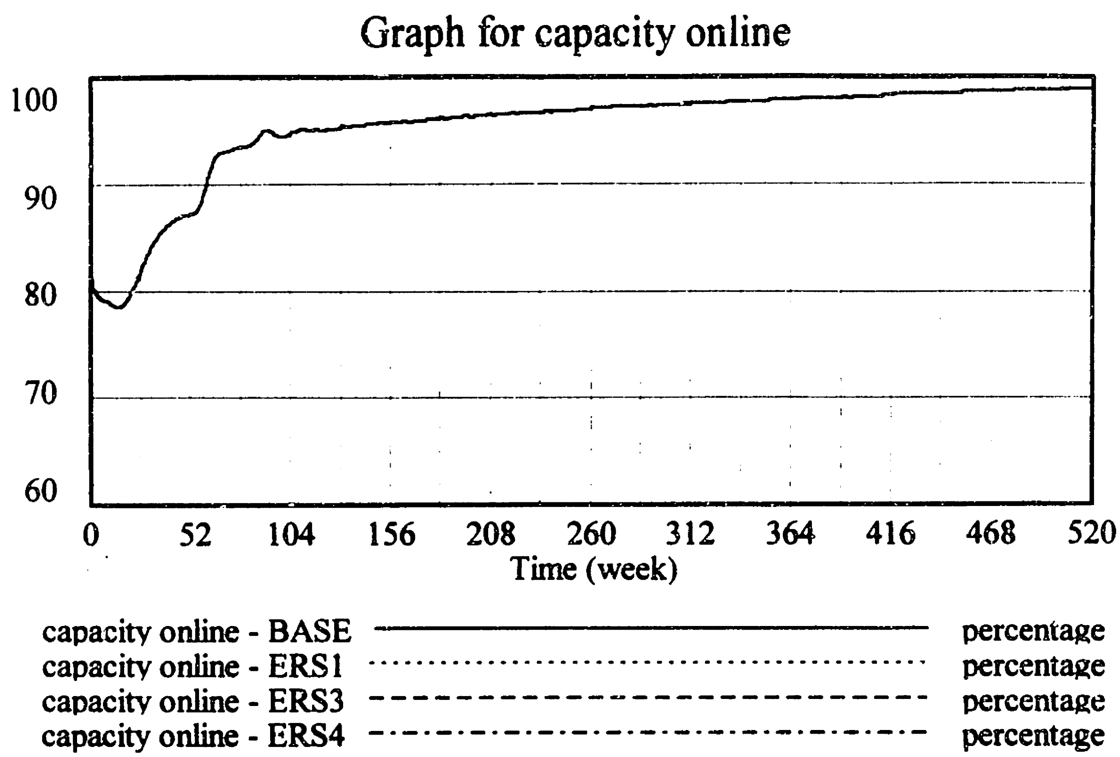
Variable 89



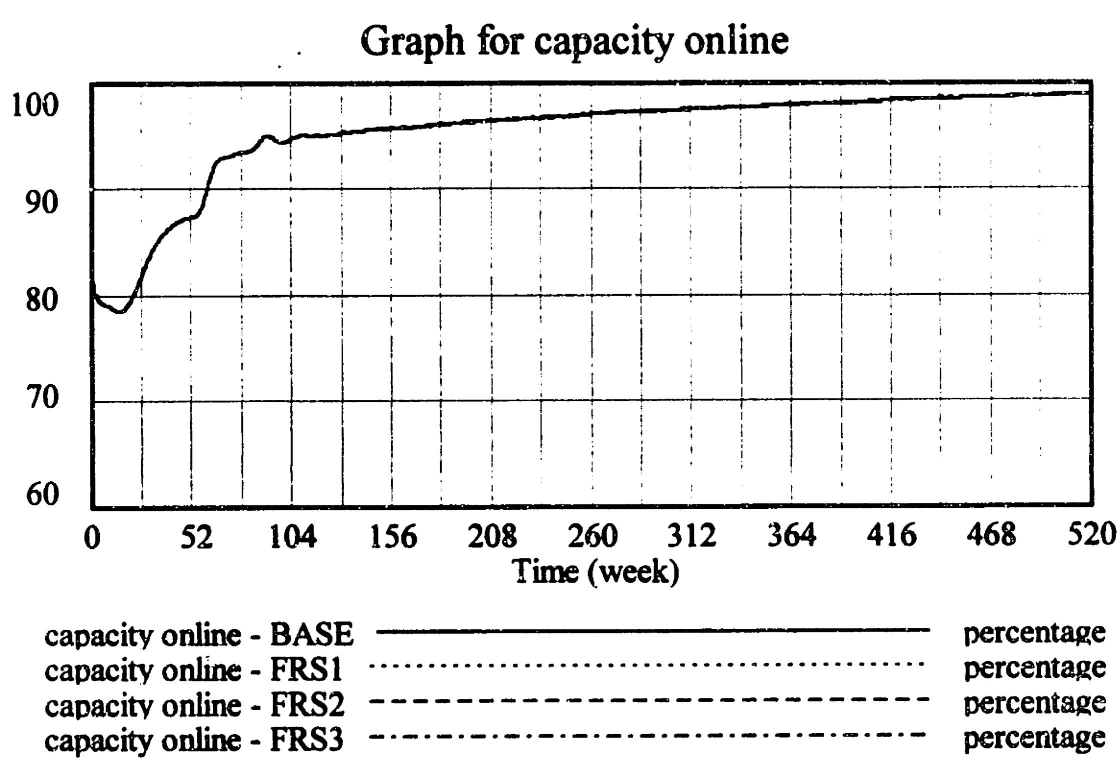
Variable 90



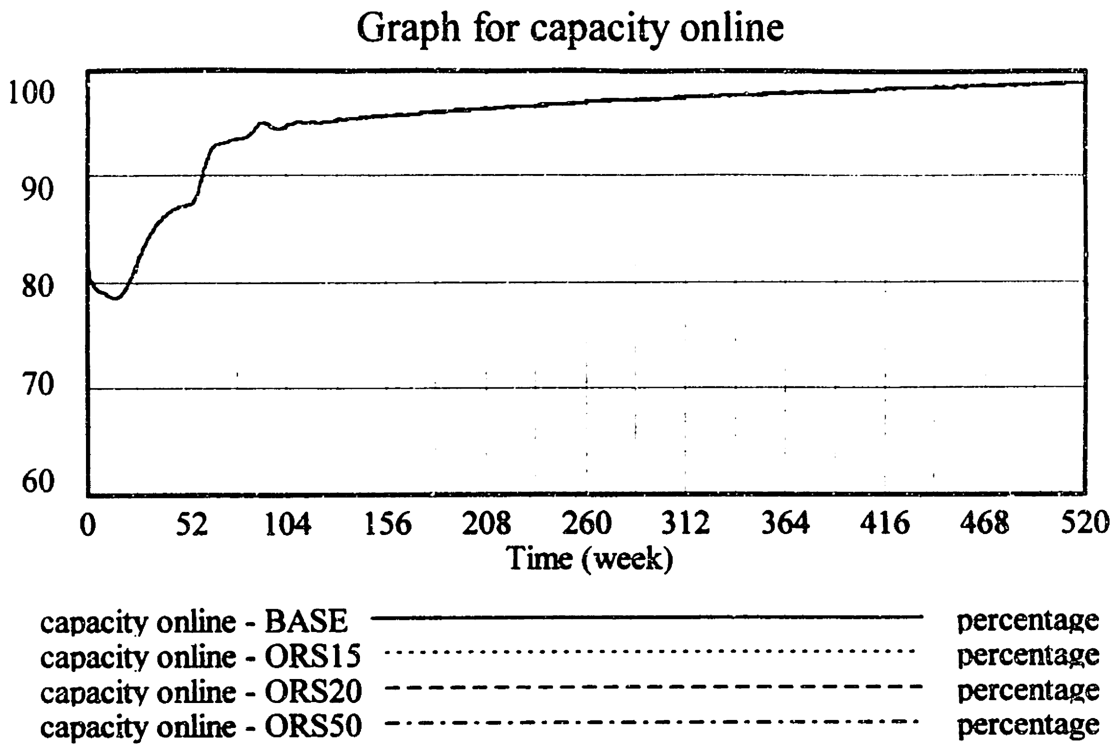
Variable 91



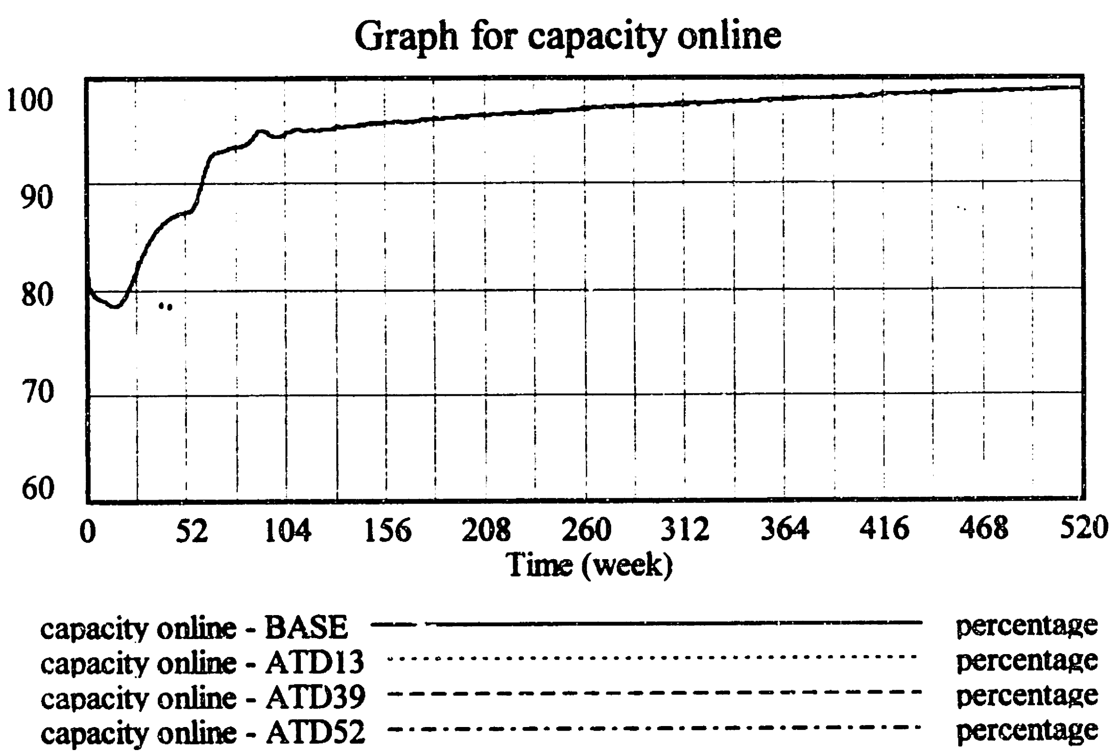
Variable 92



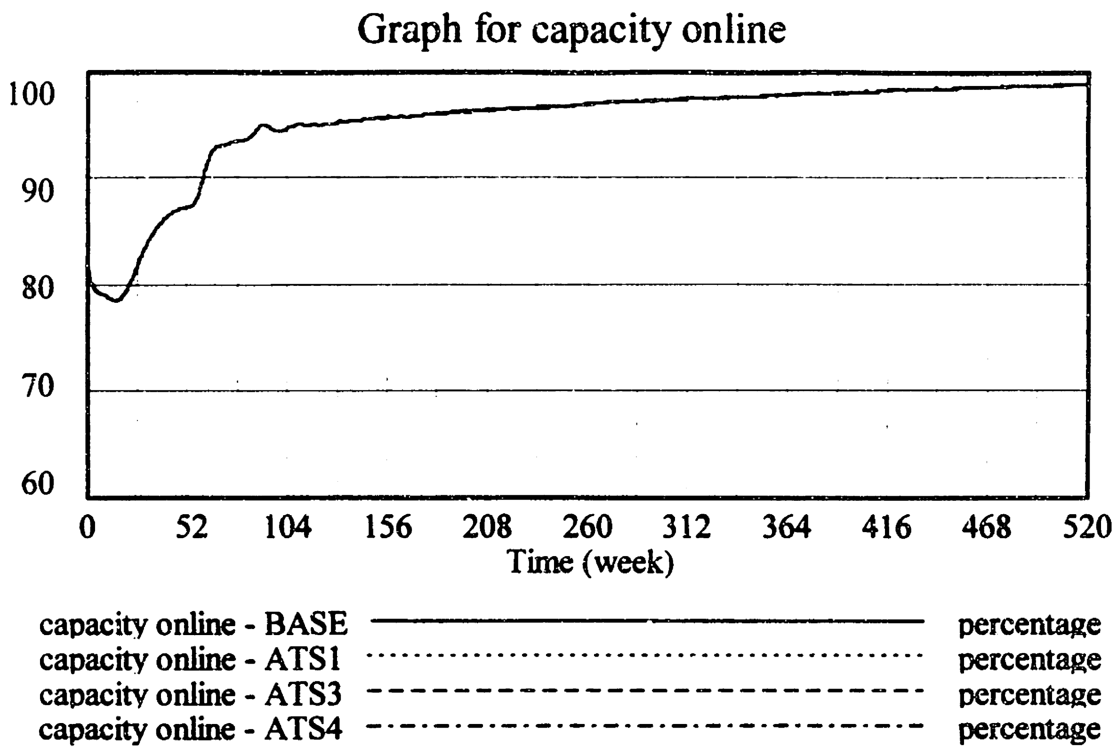
Variable 93



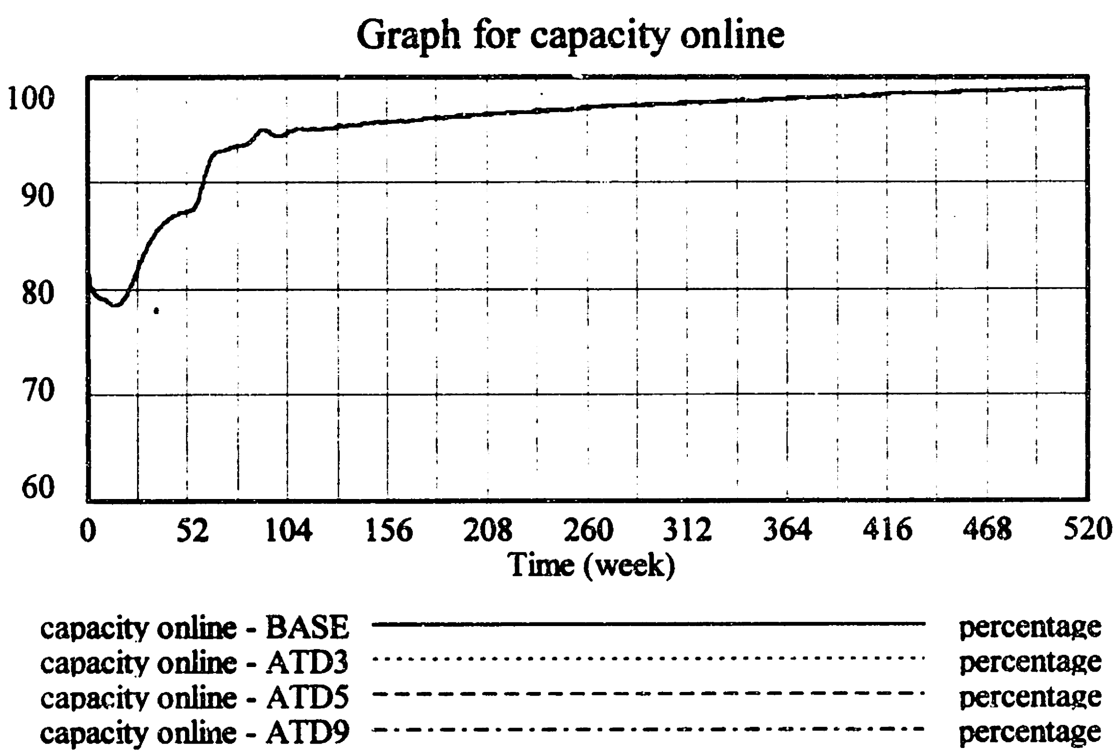
Variable 94



Variable 95

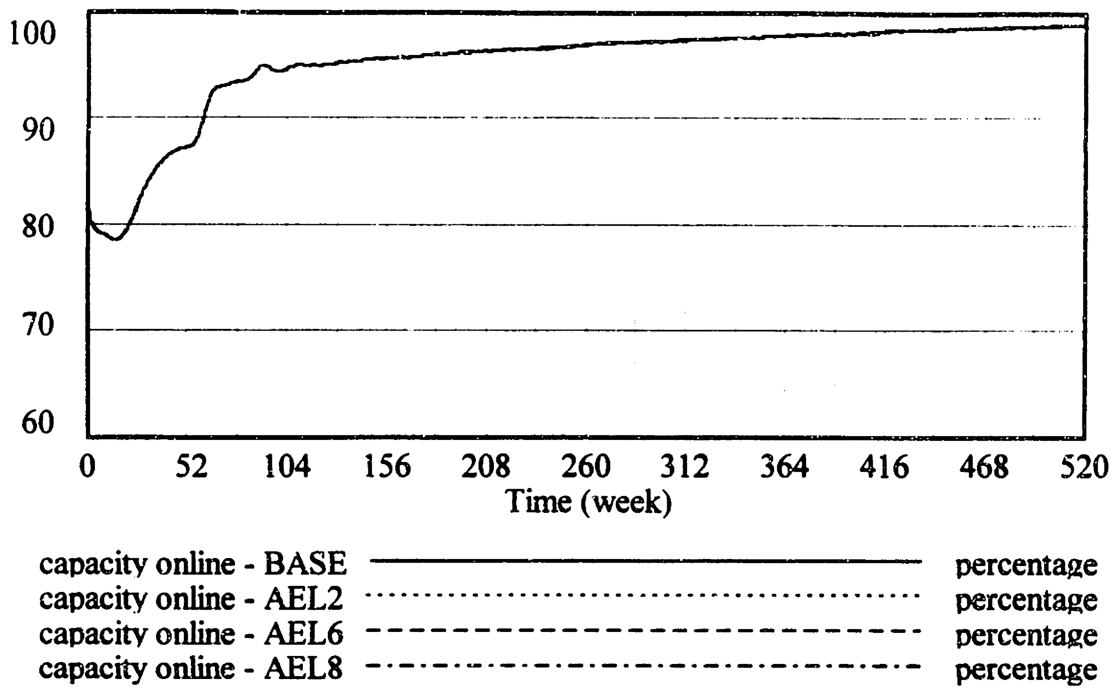


Variable 96



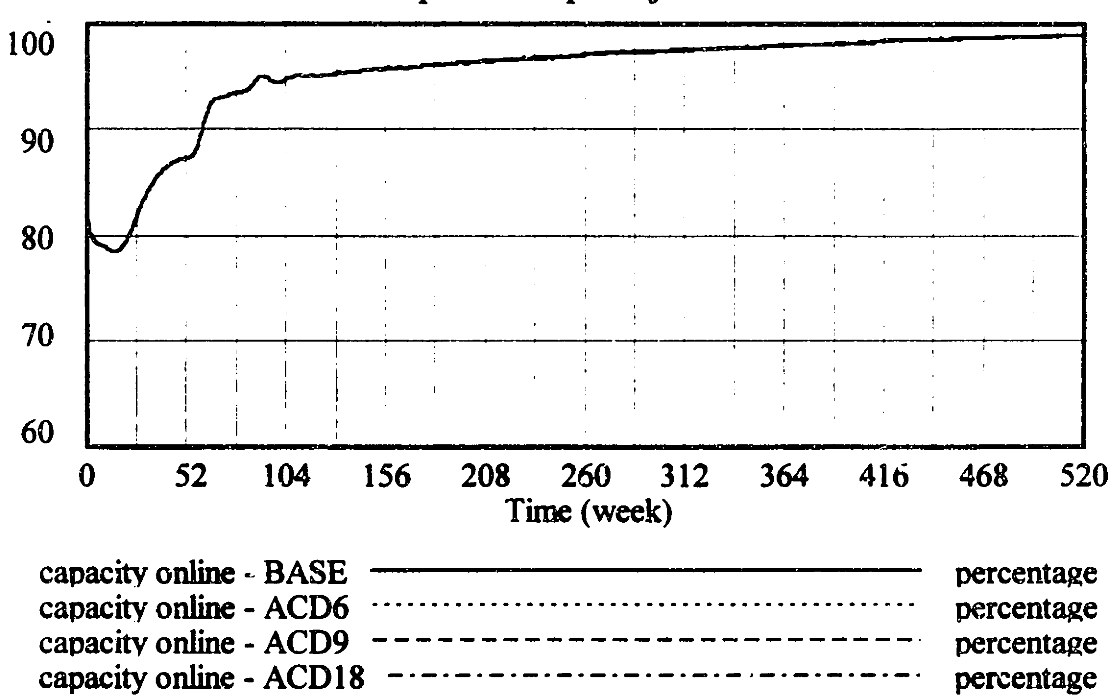
Variable 97

Graph for capacity online



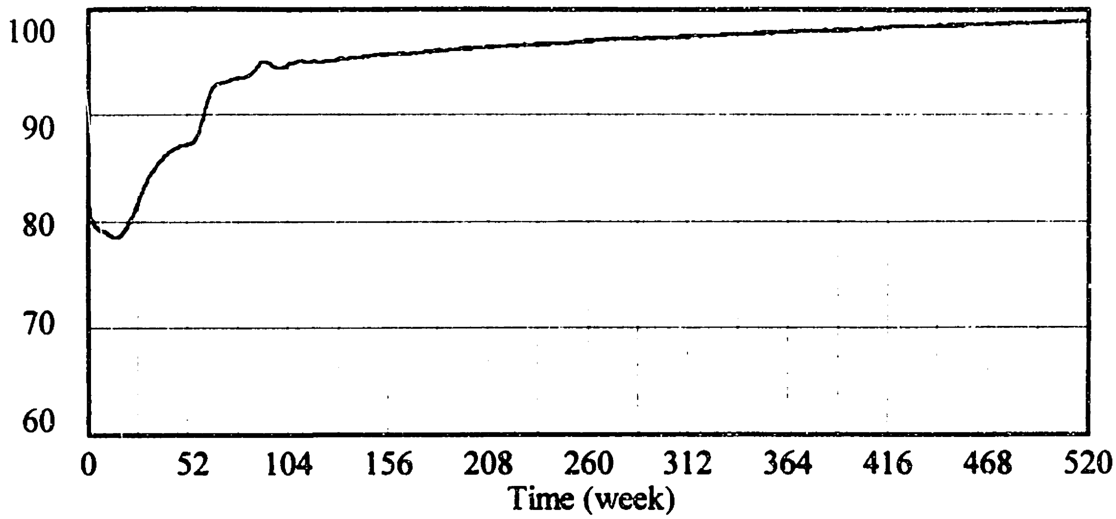
Variable 98

Graph for capacity online



Variable 99

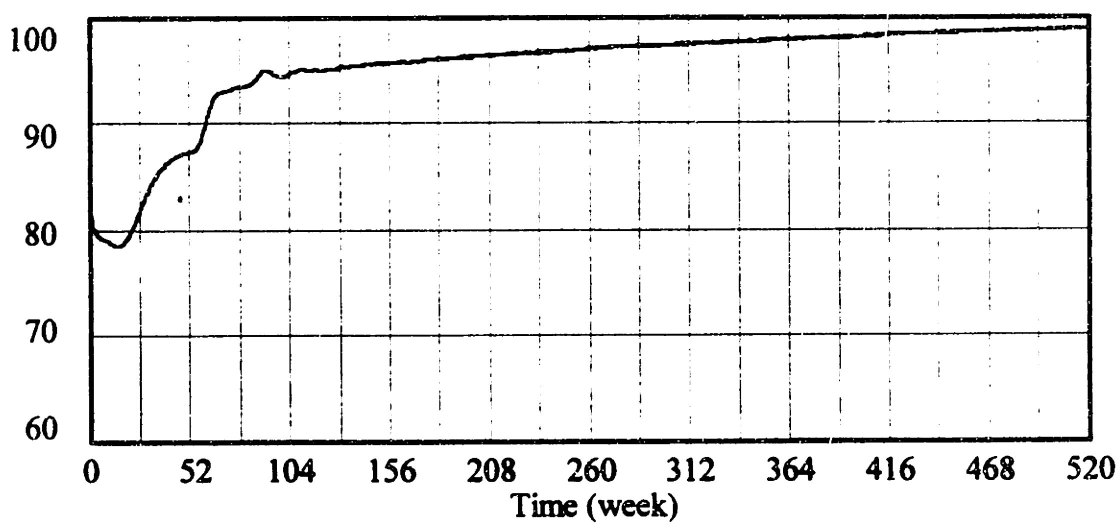
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - FCF03 ········ percentage
capacity online - FCF04 - - - - - percentage
capacity online - FCF07 -·-·-·-· percentage

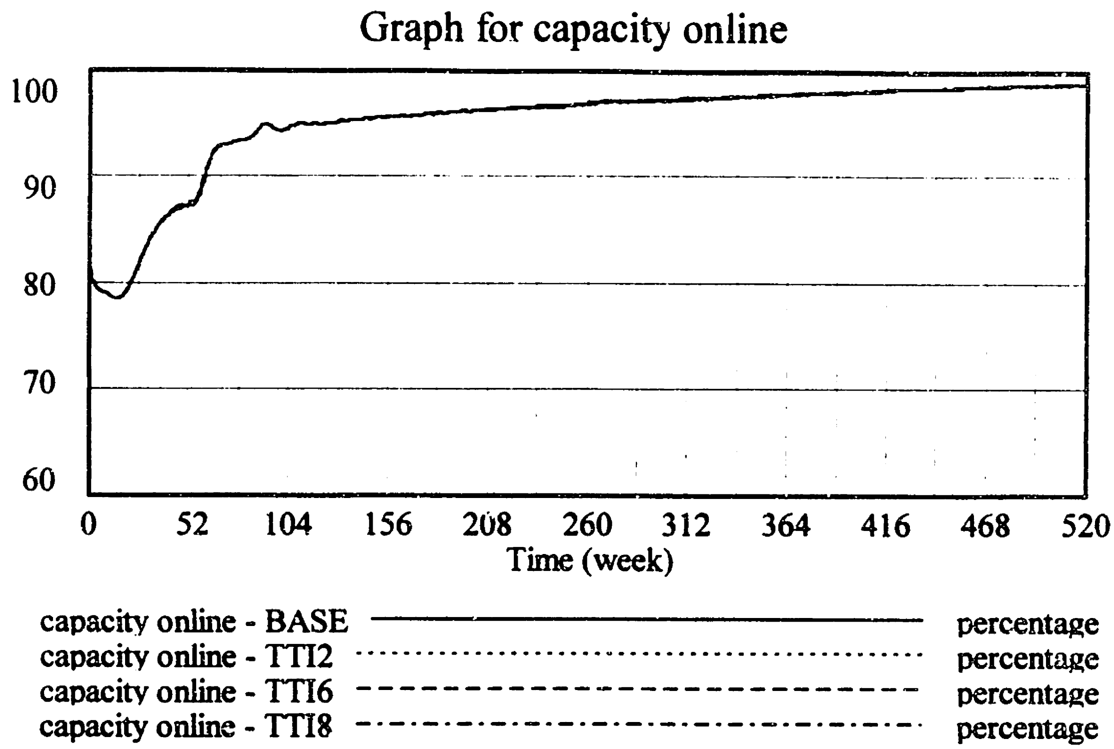
Variable 100

Graph for capacity online

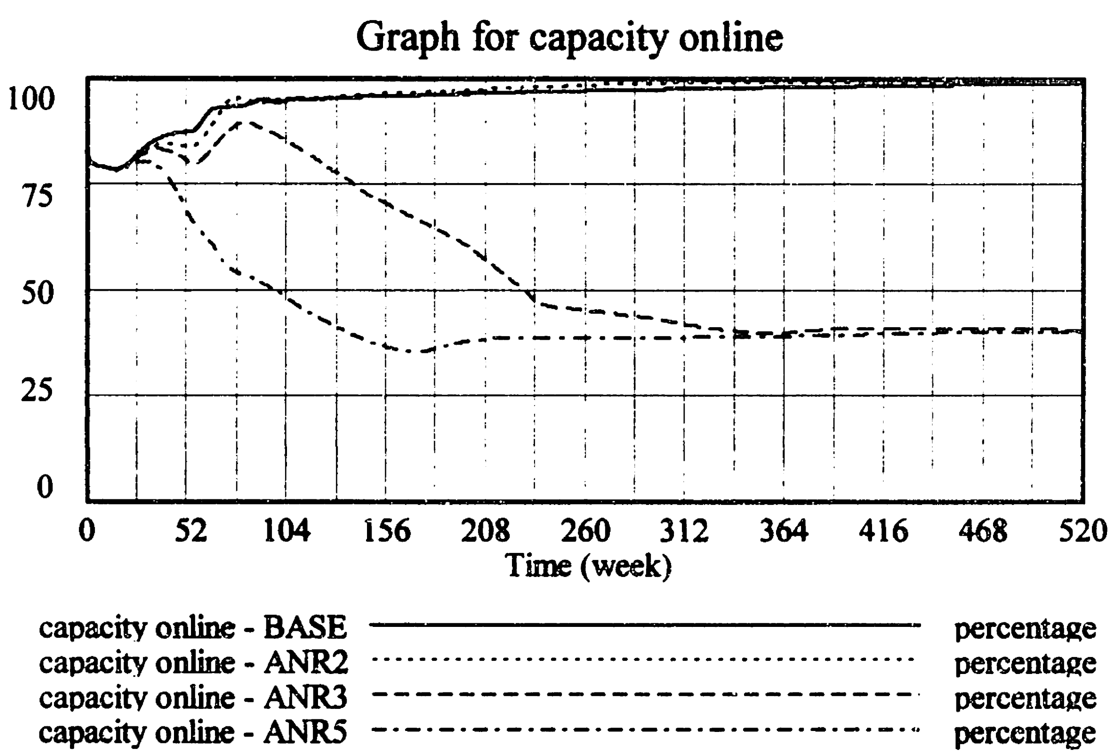


capacity online - BASE ——— percentage
capacity online - BIR1 ········ percentage
capacity online - BIR2 - - - - - percentage
capacity online - BIR5 -·-·-·-· percentage

Variable 101

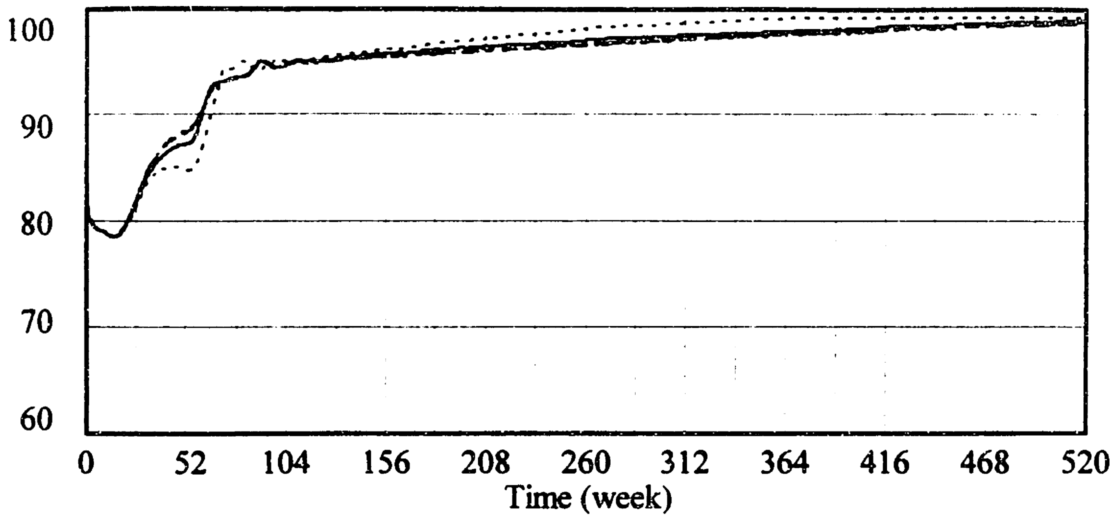


Variable 102



Variable 103

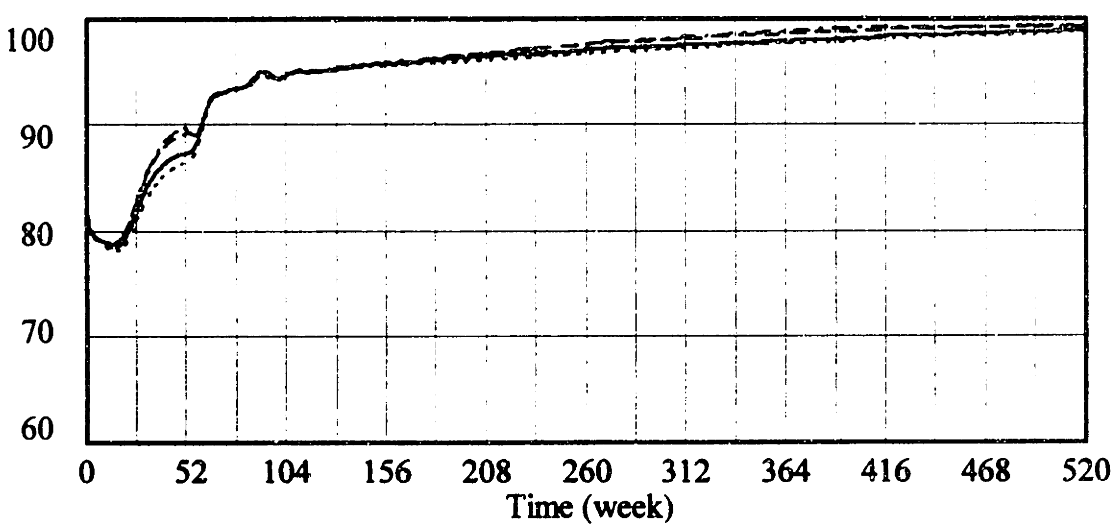
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - ARP05 ······ percentage
capacity online - ARP20 – – – percentage
capacity online - ARP30 –·–·– percentage

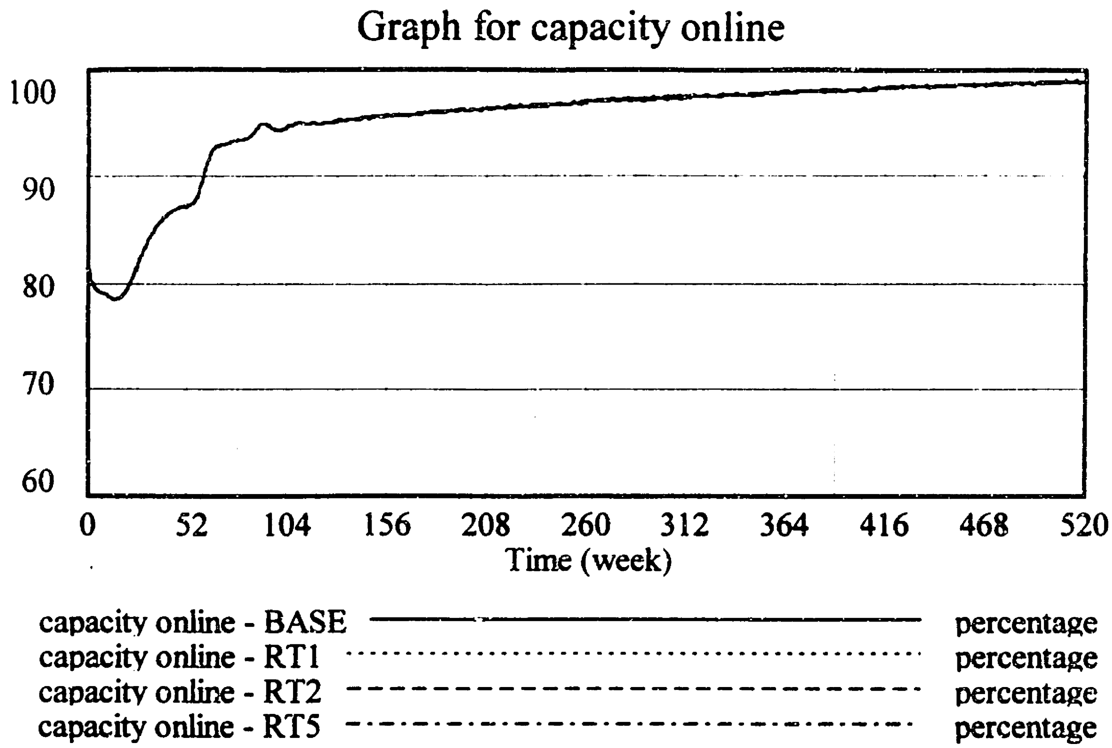
Variable 104

Graph for capacity online

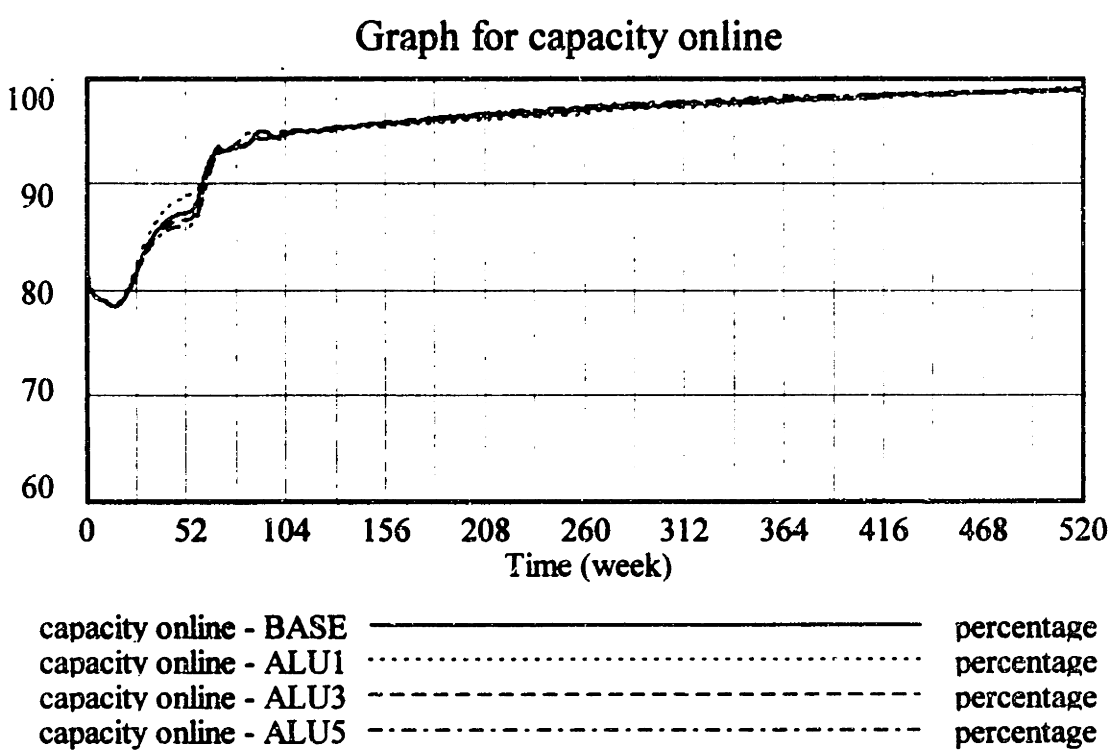


capacity online - BASE ——— percentage
capacity online - APR05 ······ percentage
capacity online - APR20 – – – percentage
capacity online - APR30 –·–·– percentage

Variable 105

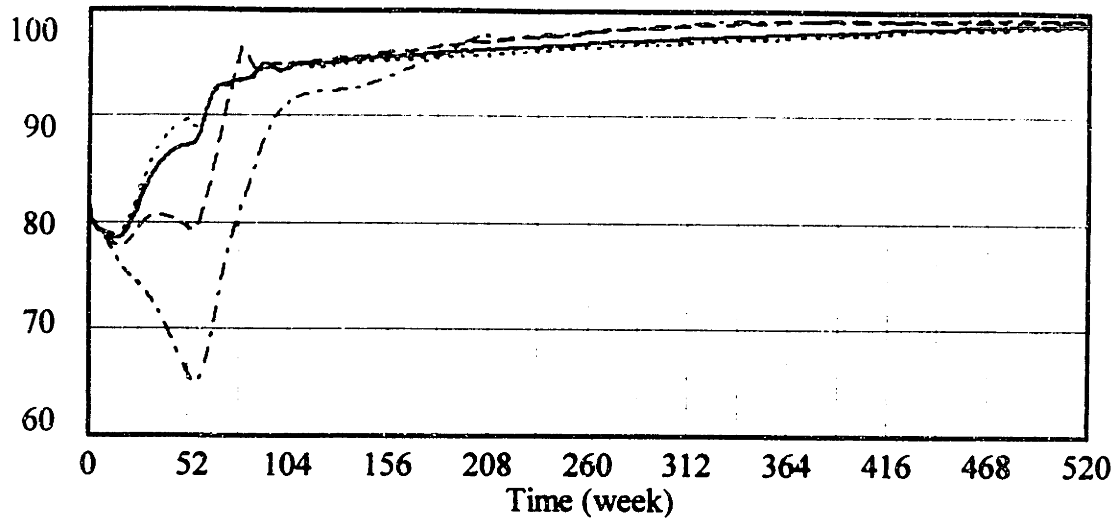


Variable 106



Variable 107

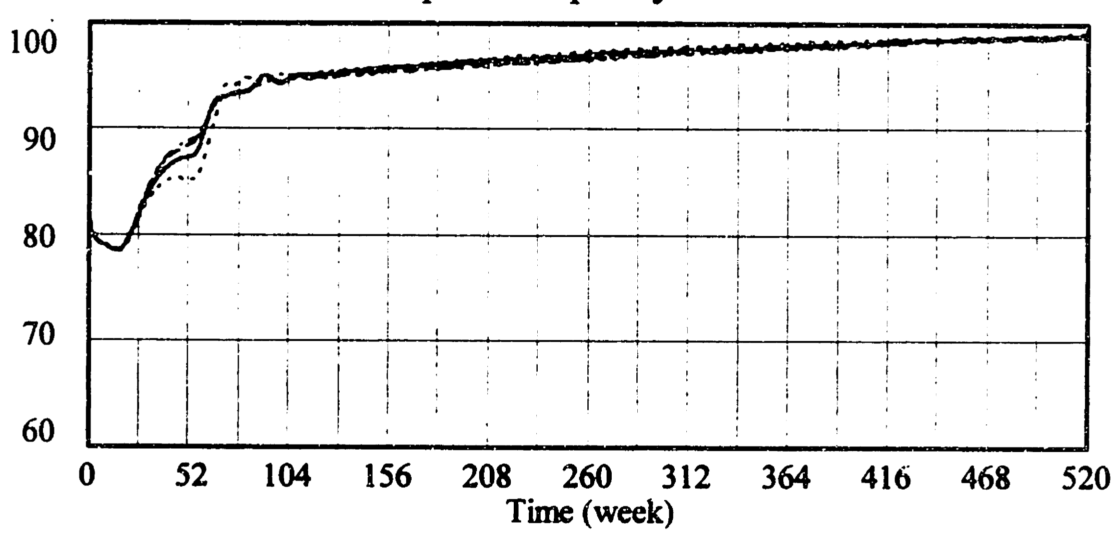
Graph for capacity online



capacity online - BASE ———————— percentage
capacity online - ARS005 ··········· percentage
capacity online - ARS02 – – – – – – percentage
capacity online - ARS03 –·–·–·–·–· percentage

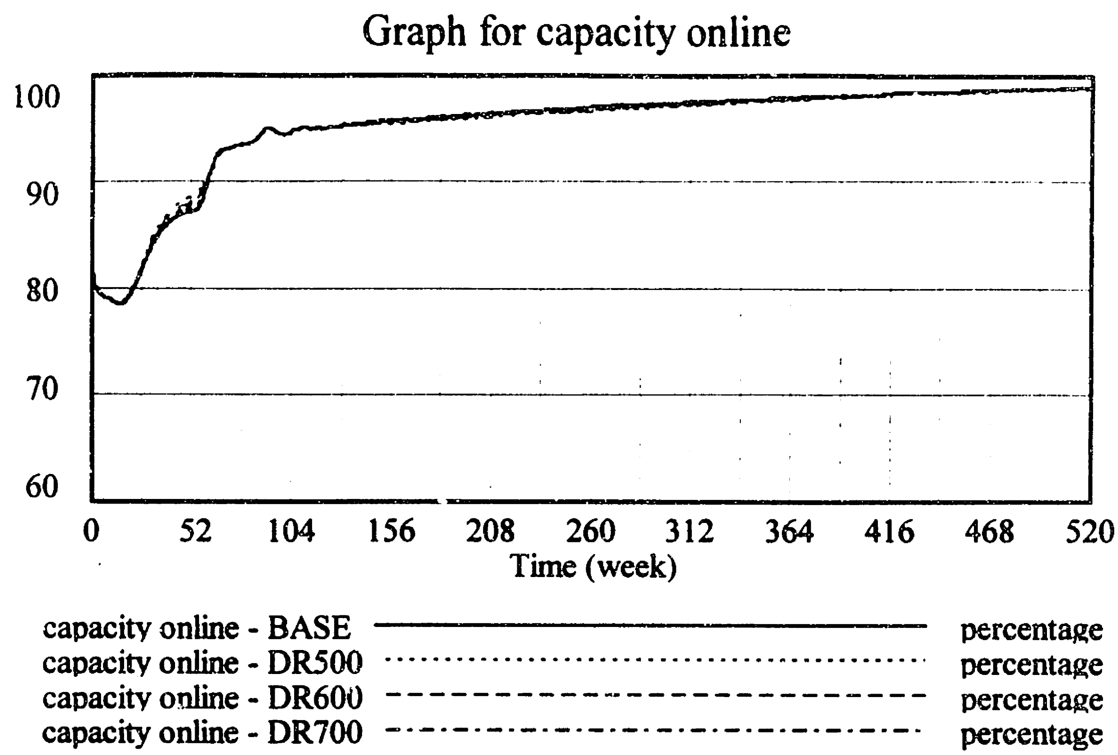
Variable 108

Graph for capacity online

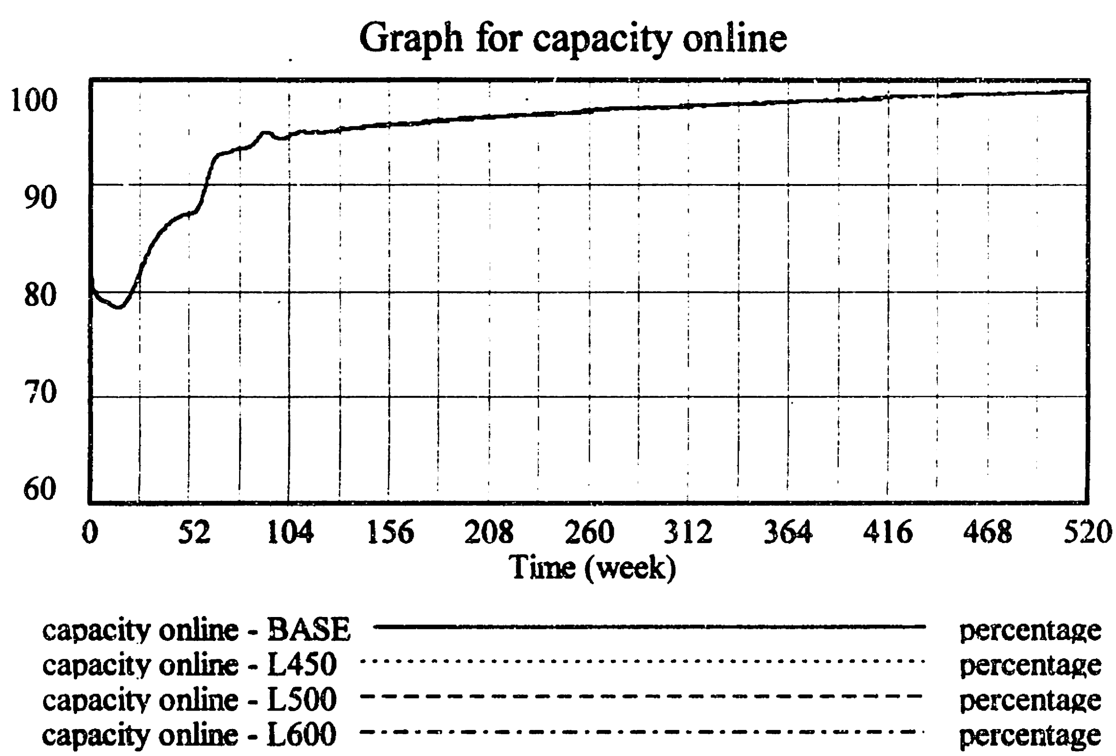


capacity online - BASE ———————— percentage
capacity online - TTE05 ··········· percentage
capacity online - TTE20 – – – – – – percentage
capacity online - TTE30 –·–·–·–·–· percentage

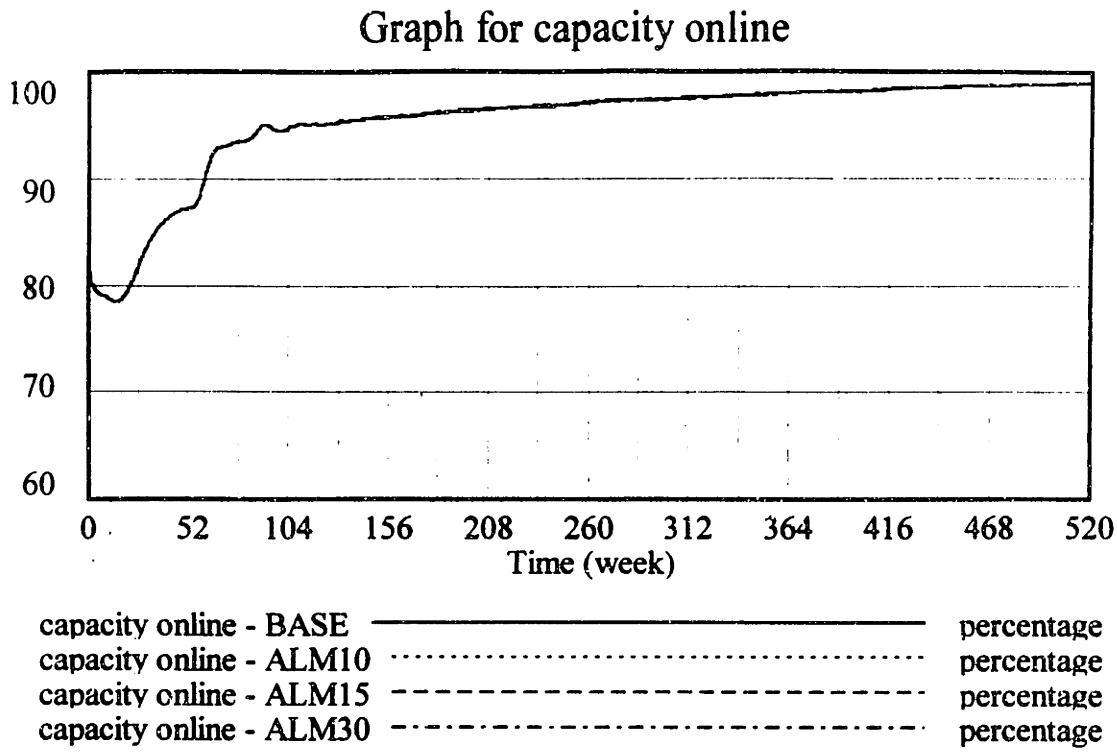
Variable 109



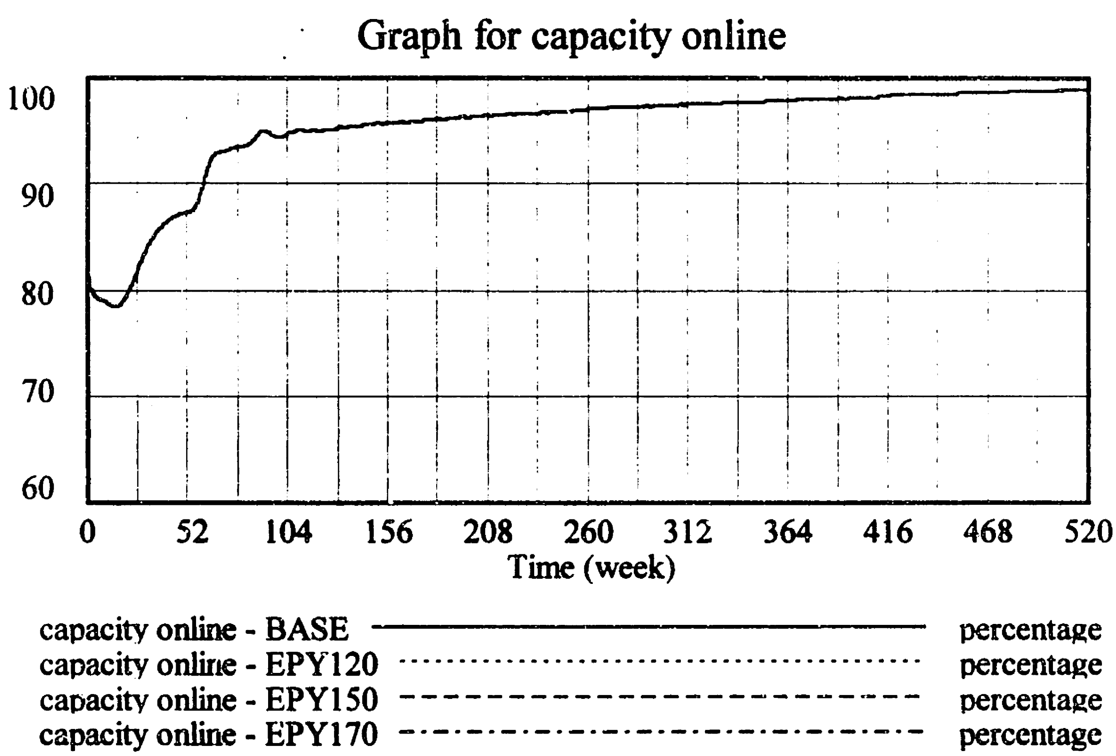
Variable 110



Variable 111

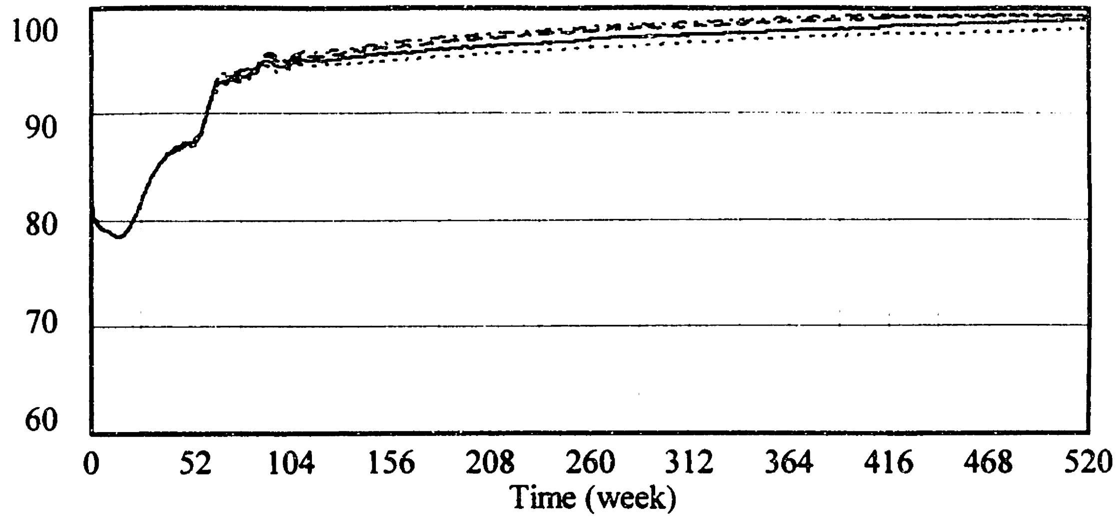


Variable 112



Variable 113

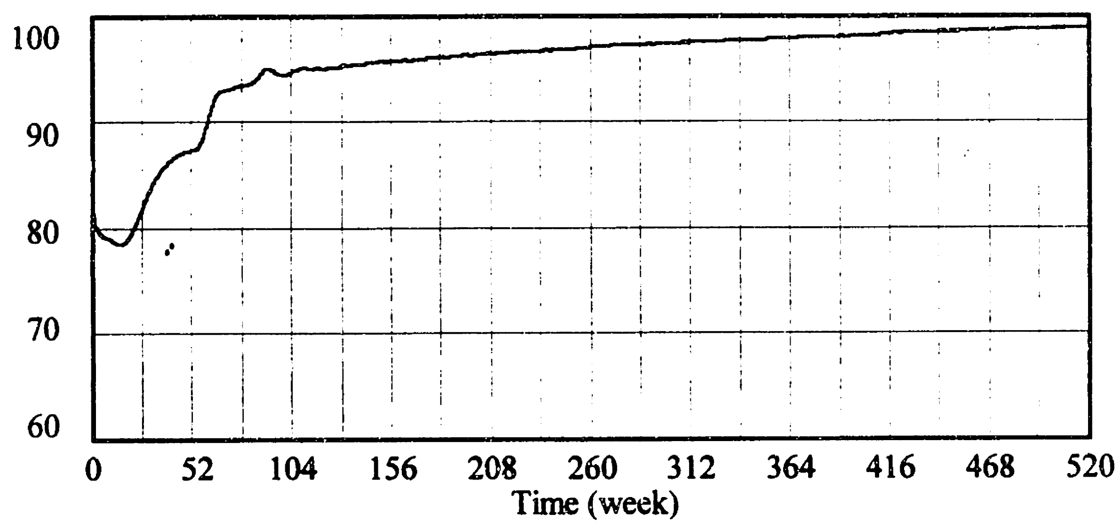
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - PDA5 ········ percentage
capacity online - PDA15 - - - - percentage
capacity online - PDA20 -·-·-·- percentage

Variable 114

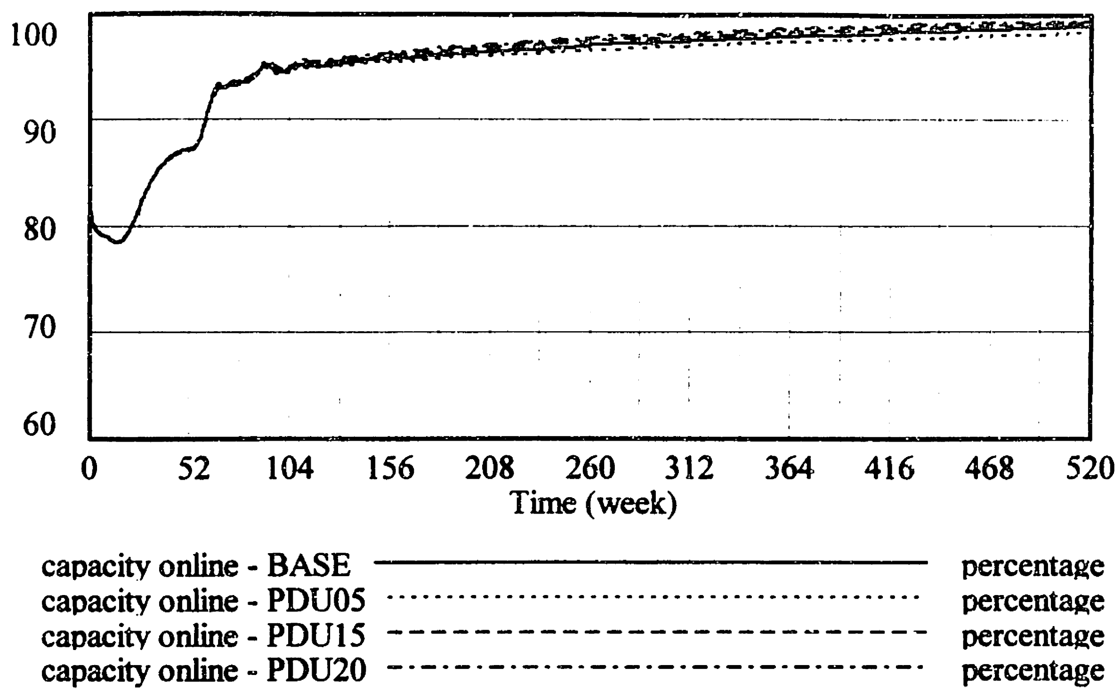
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - PDE50 ········ percentage
capacity online - PDE150 - - - - percentage
capacity online - PDE200 -·-·-·- percentage

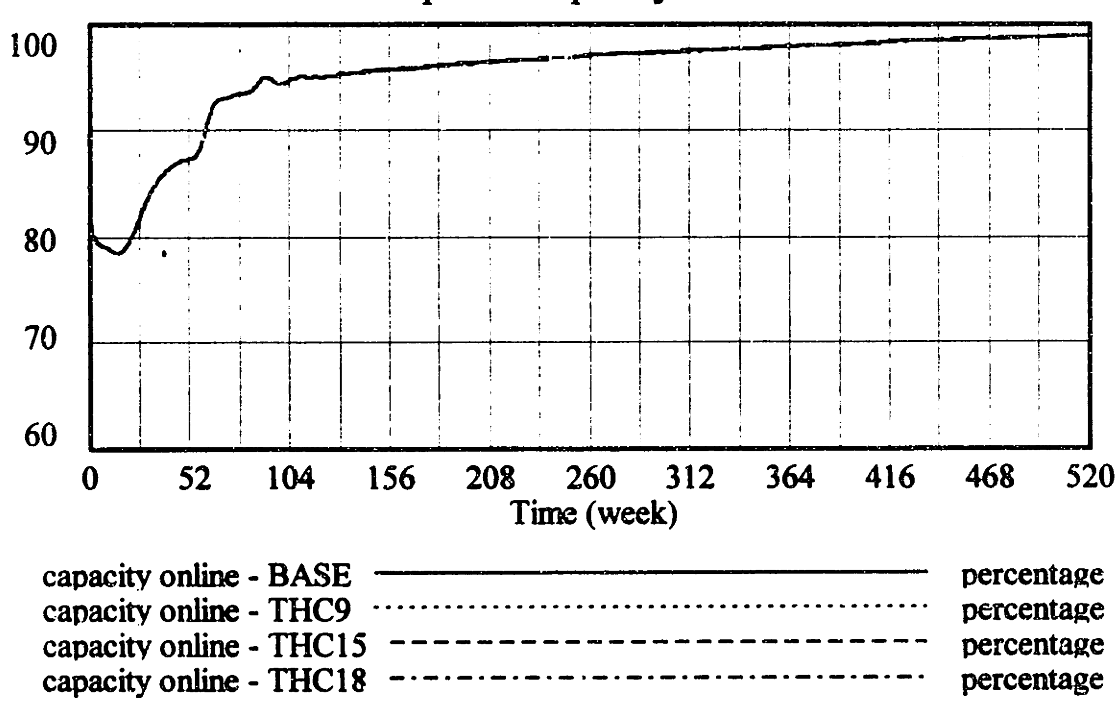
Variable 115

Graph for capacity online

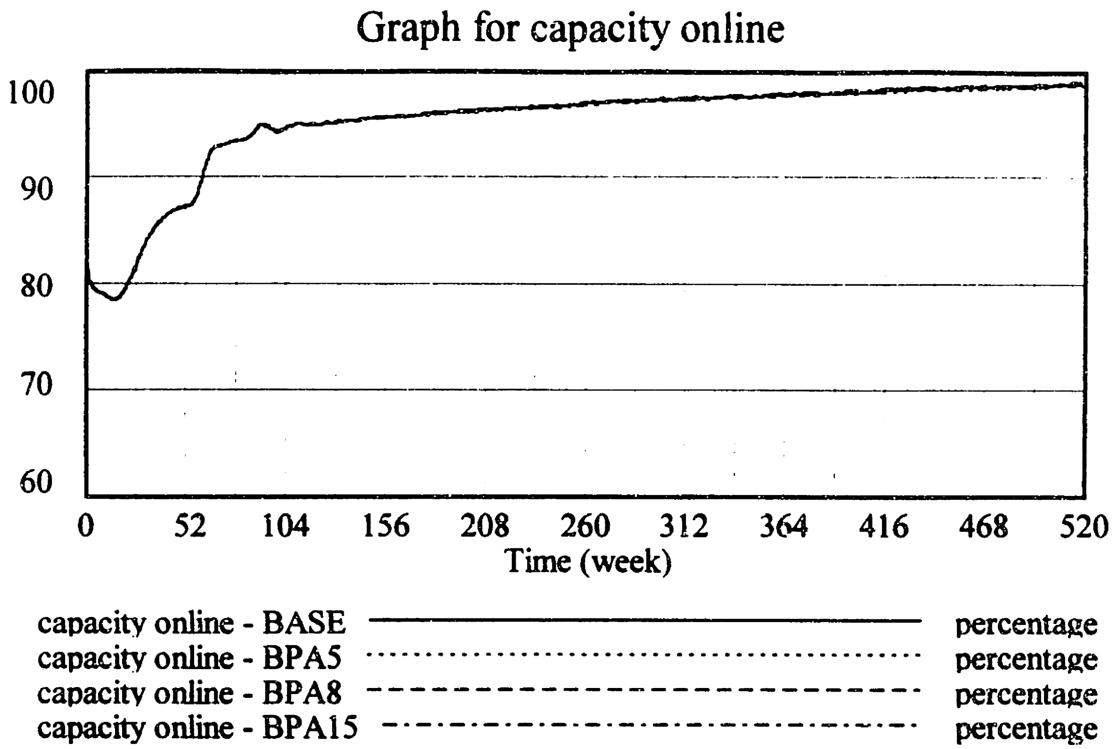


Variable 116

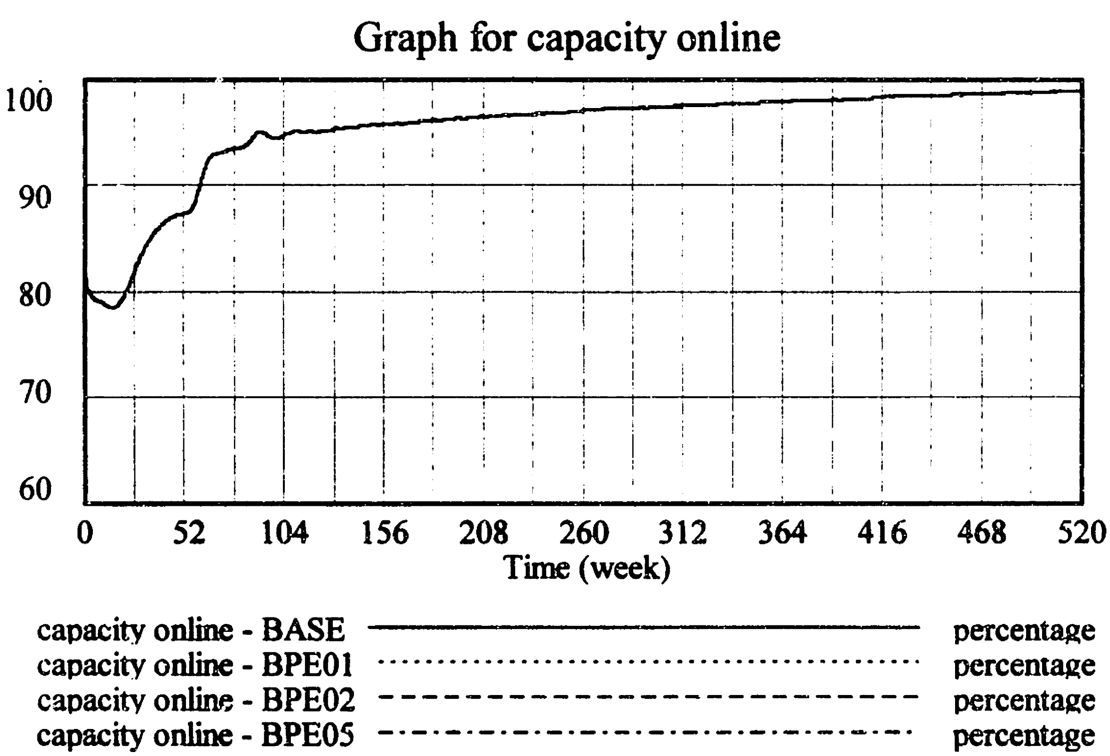
Graph for capacity online



Variable 117

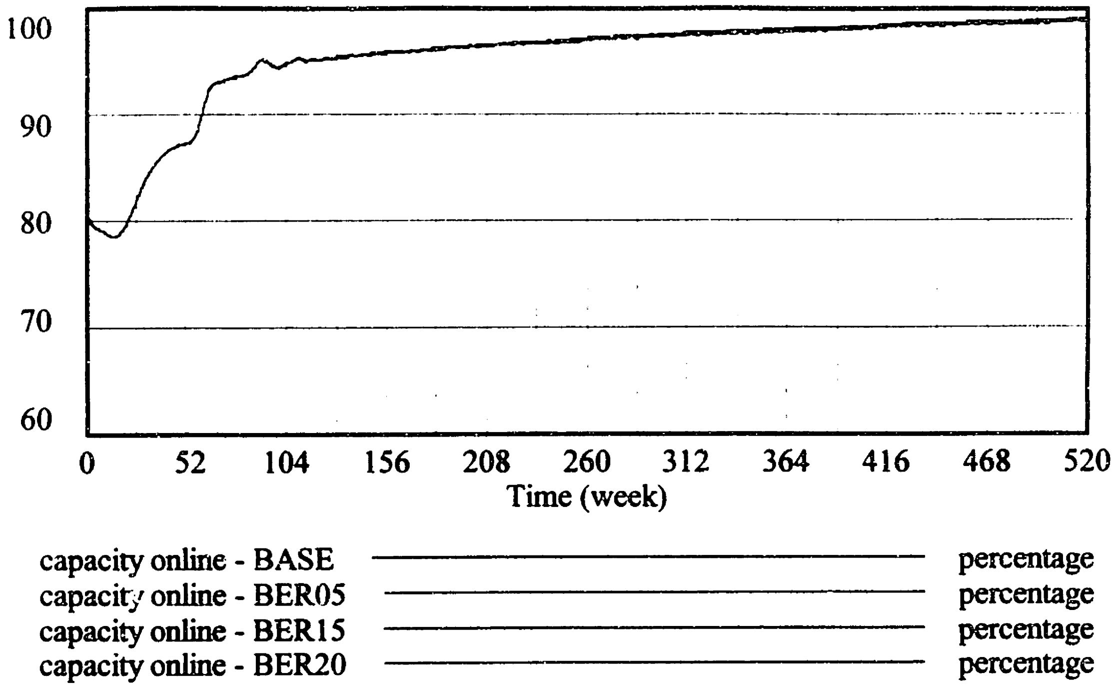


Variable 118



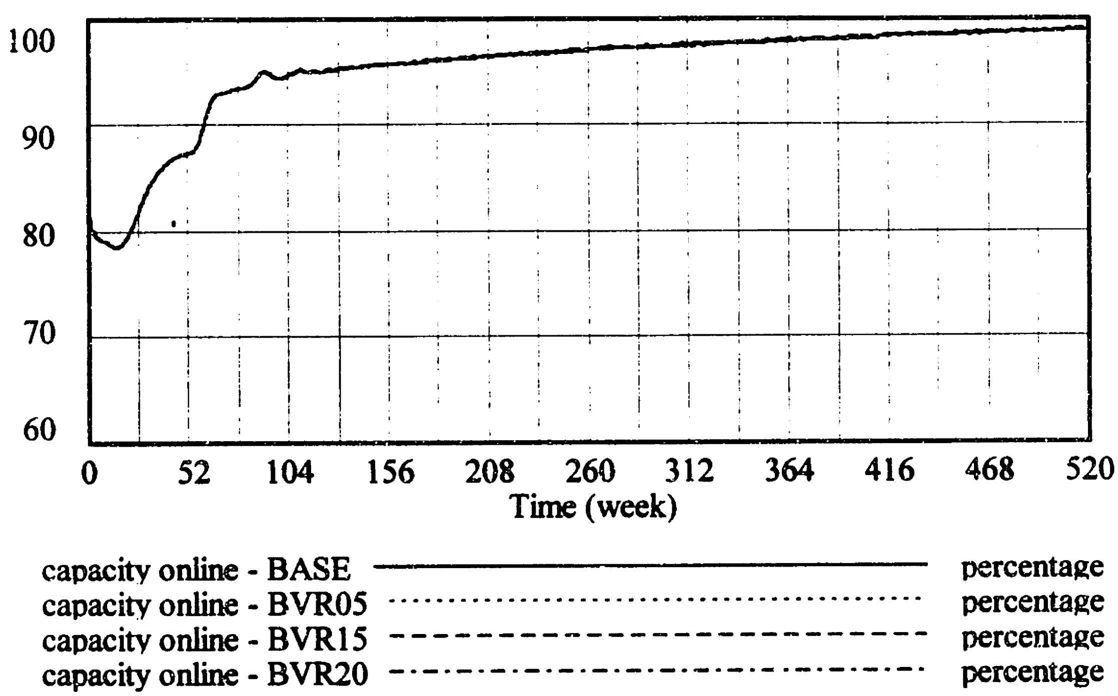
Variable 119

Graph for capacity online



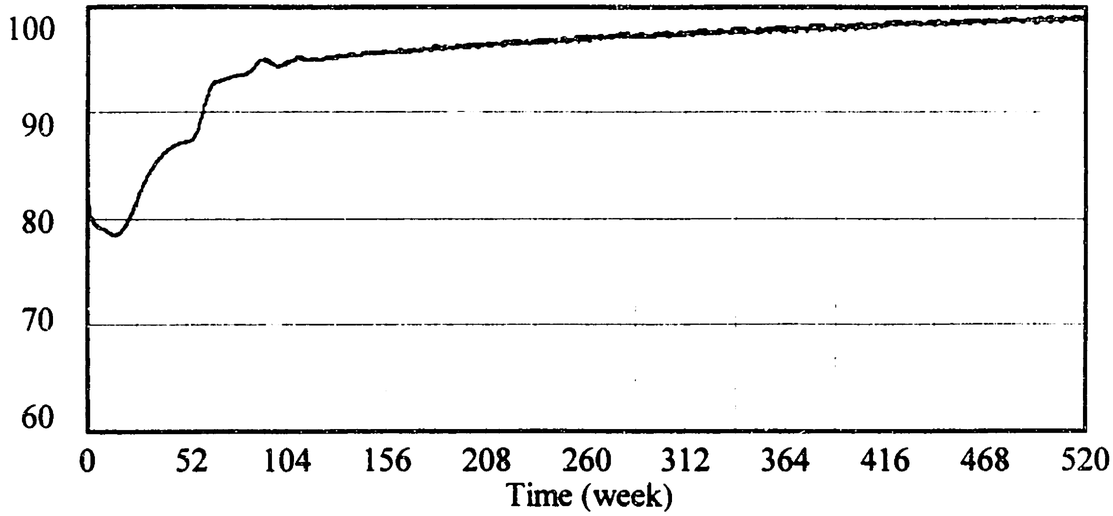
Variable 120

Graph for capacity online



Variable 121

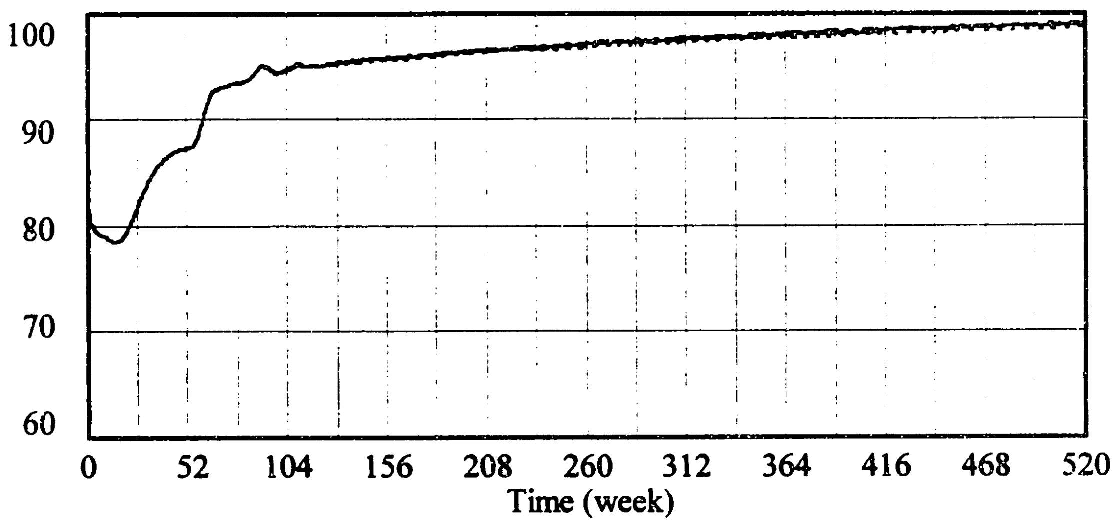
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - BWR1 ········ percentage
capacity online - BWR3 - - - - percentage
capacity online - BWR4 -·-·-·- percentage

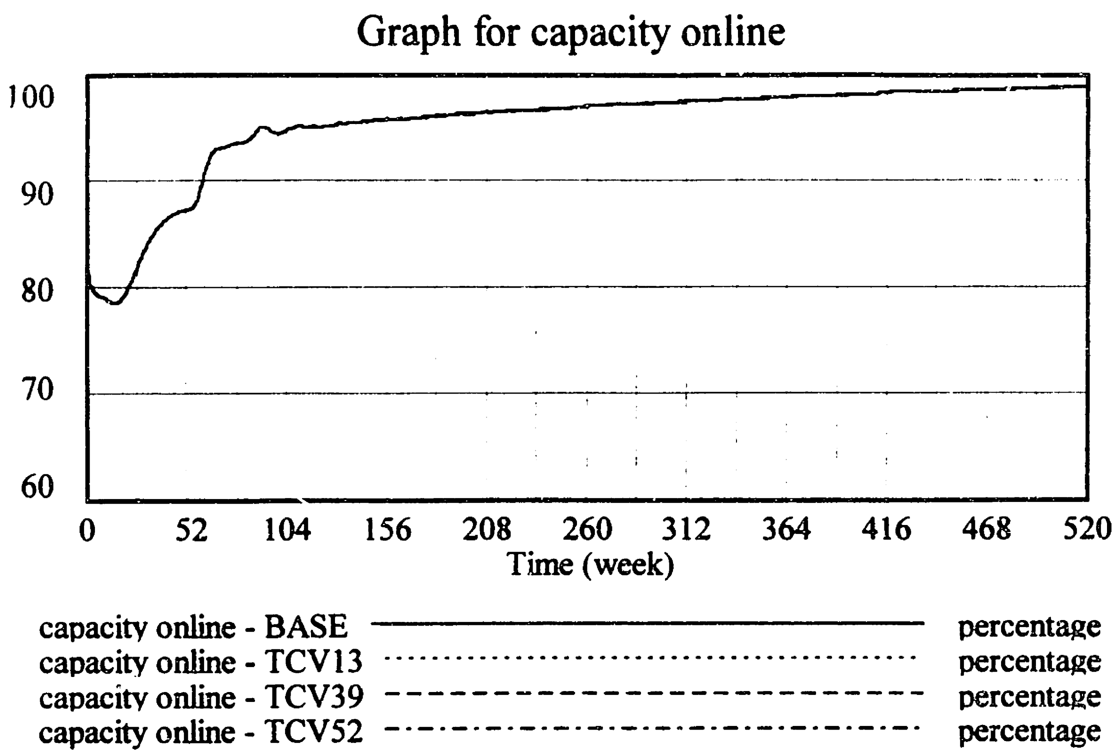
Variable 122

Graph for capacity online

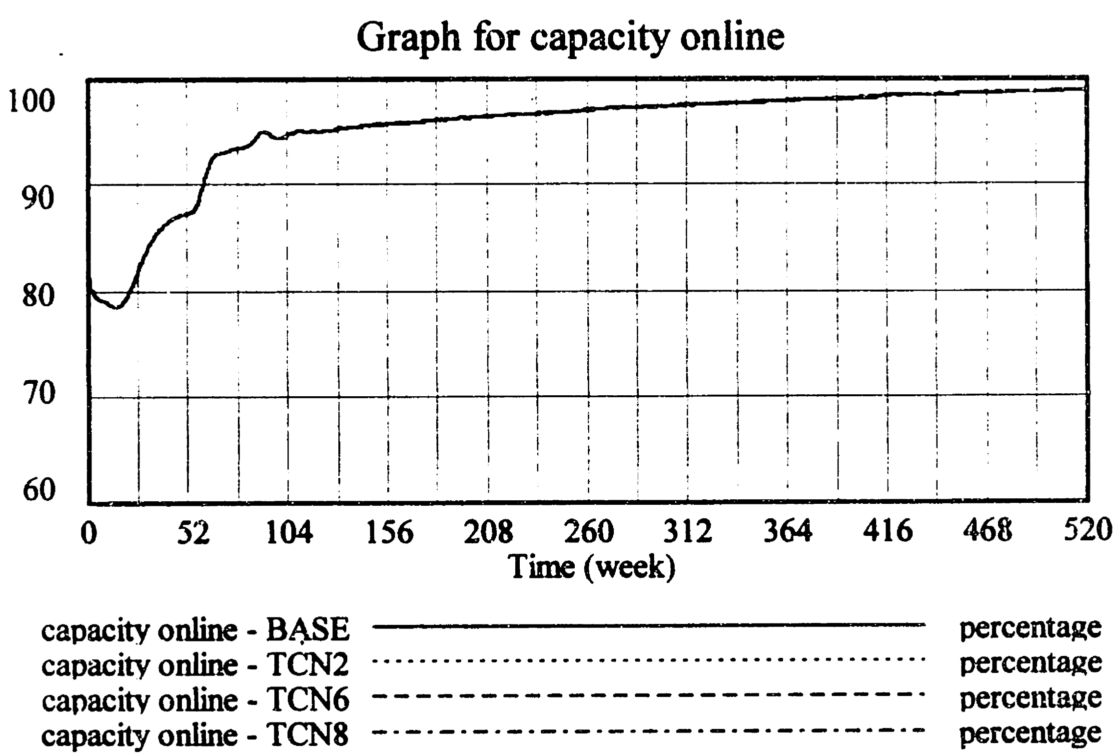


capacity online - BASE ———— percentage
capacity online - FPN025 ········ percentage
capacity online - FPN06 - - - - percentage
capacity online - FPN07 -·-·-·- percentage

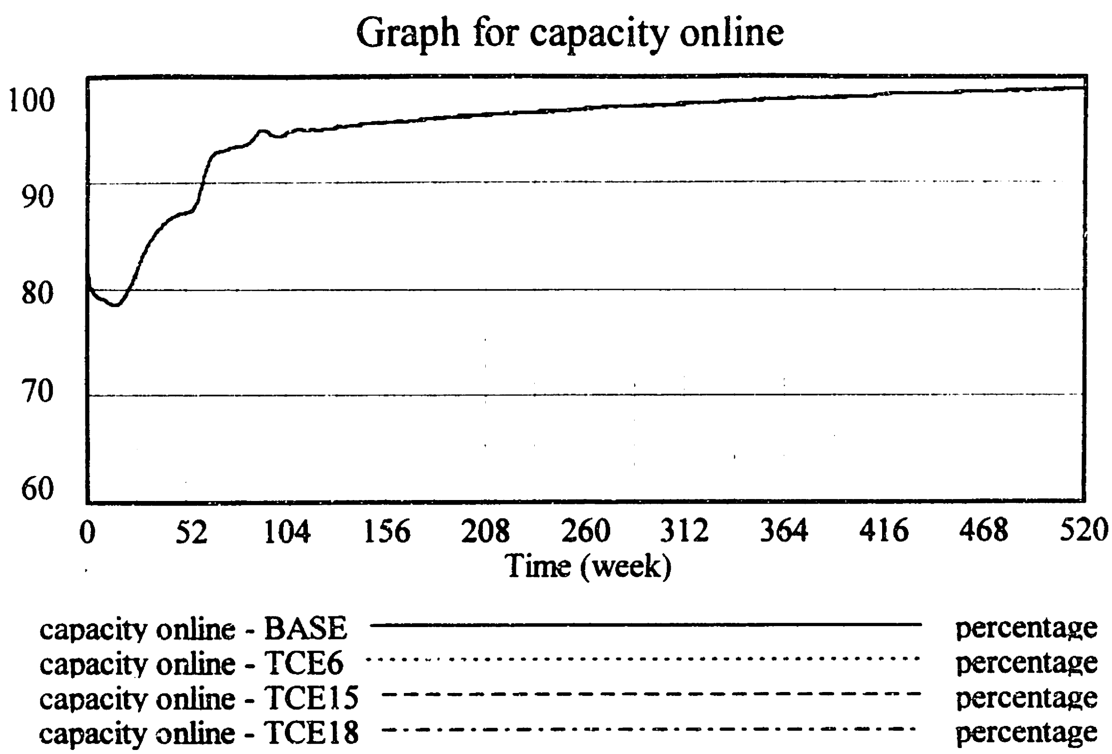
Variable 123



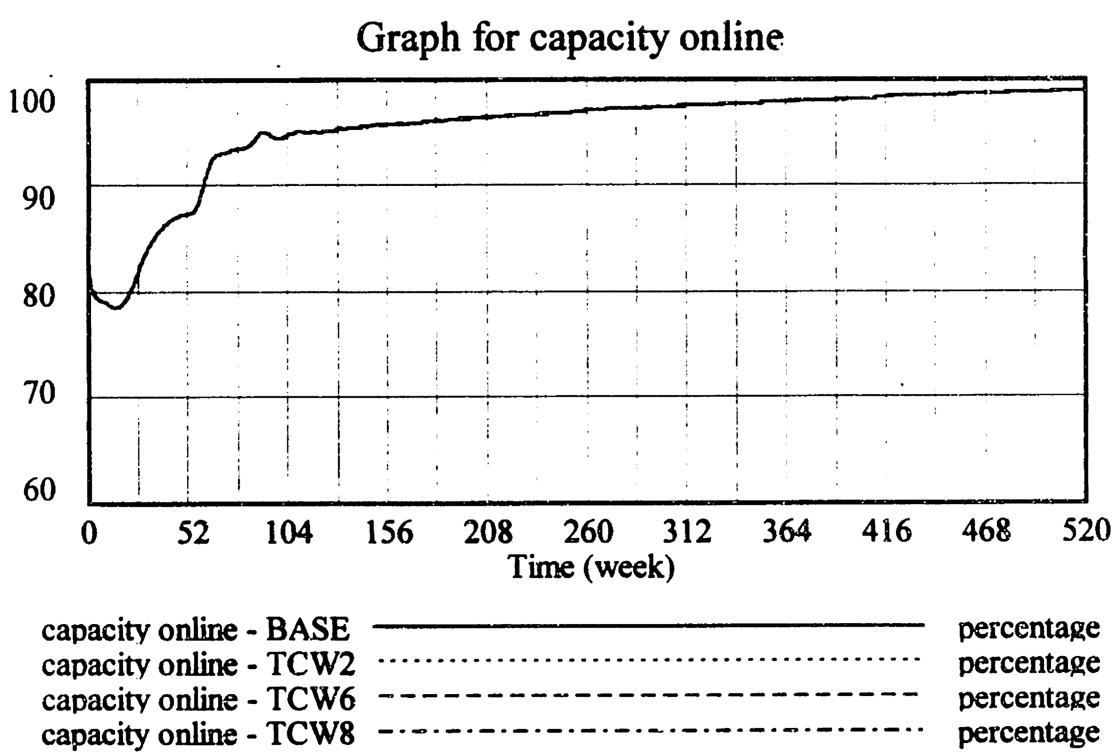
Variable 124



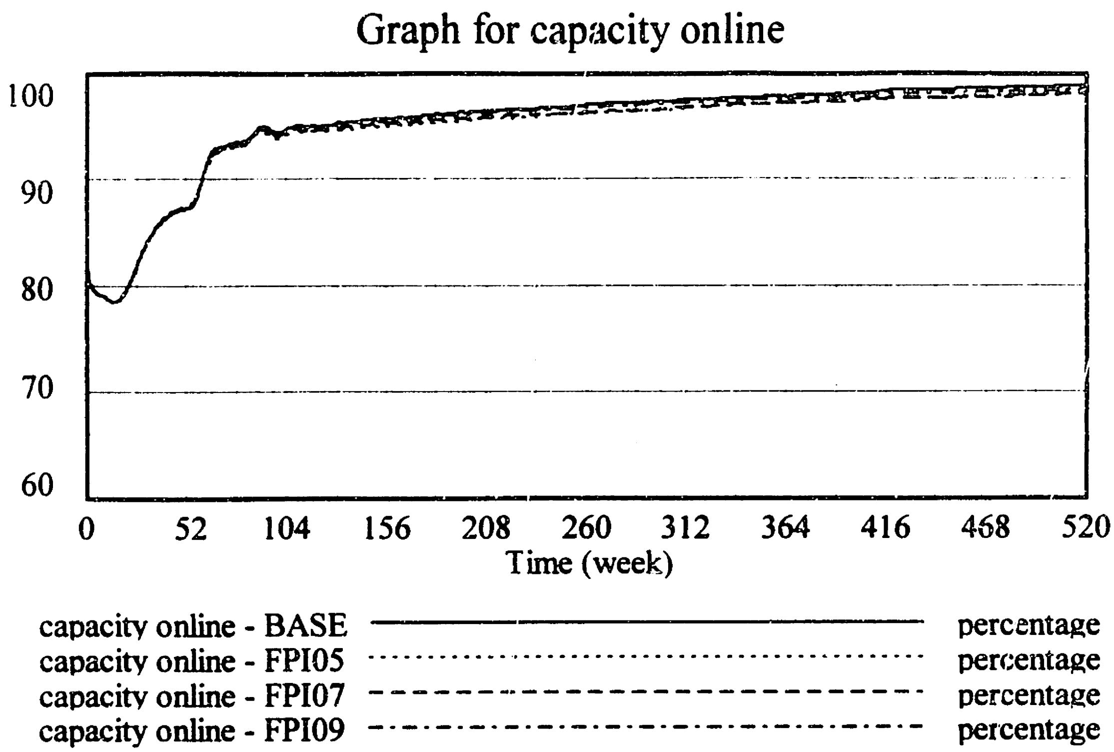
Variable 125



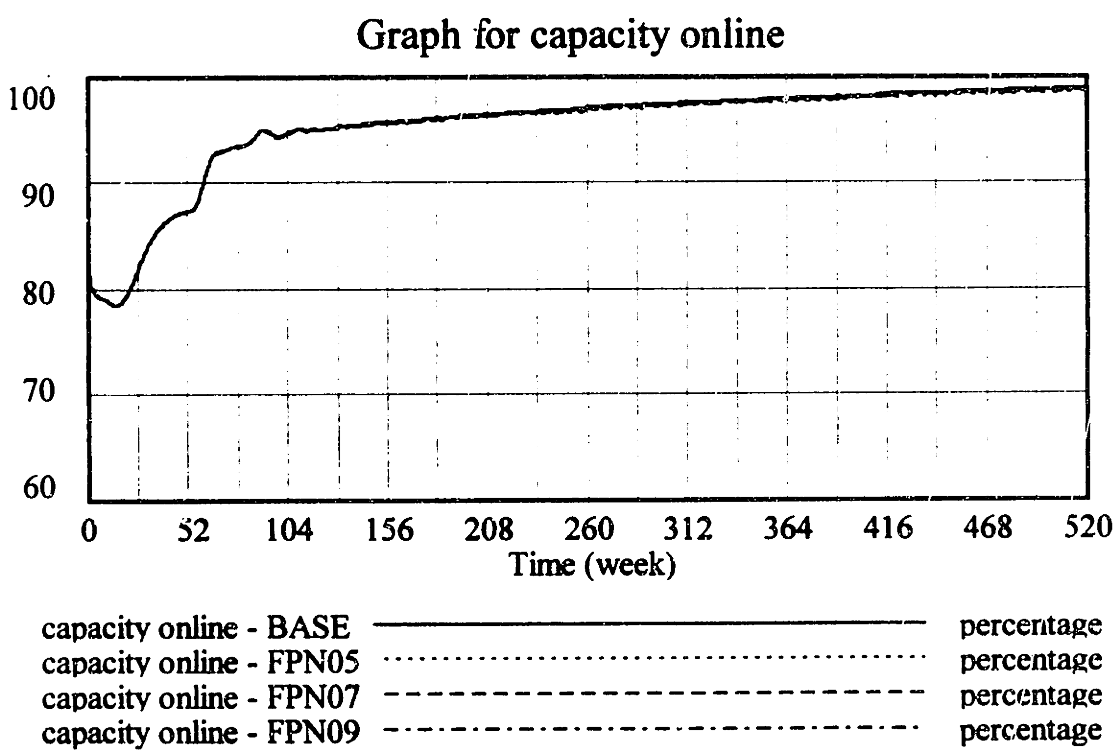
Variable 126



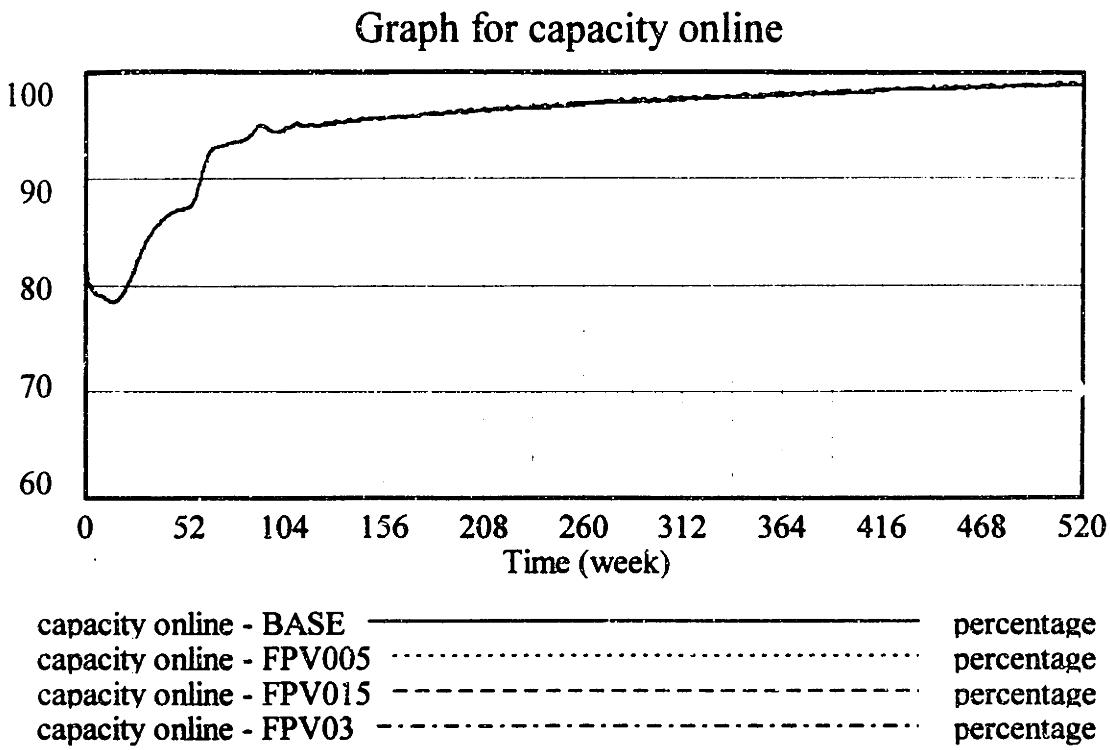
Variable 127



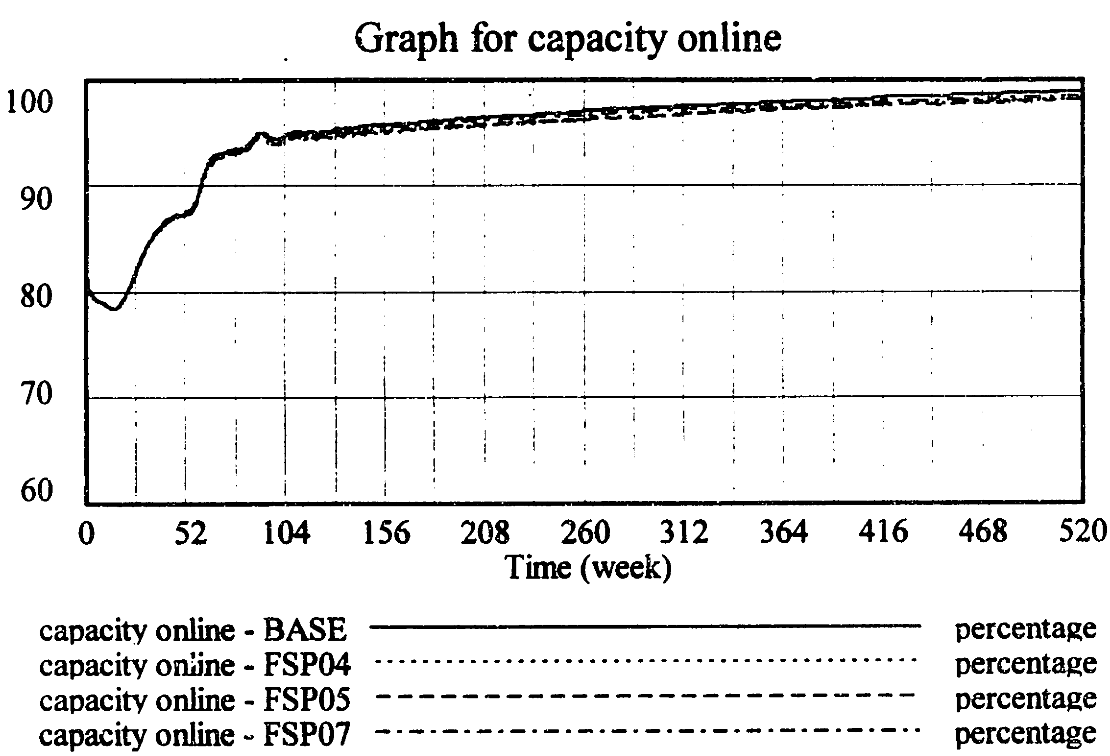
Variable 128



Variable 129

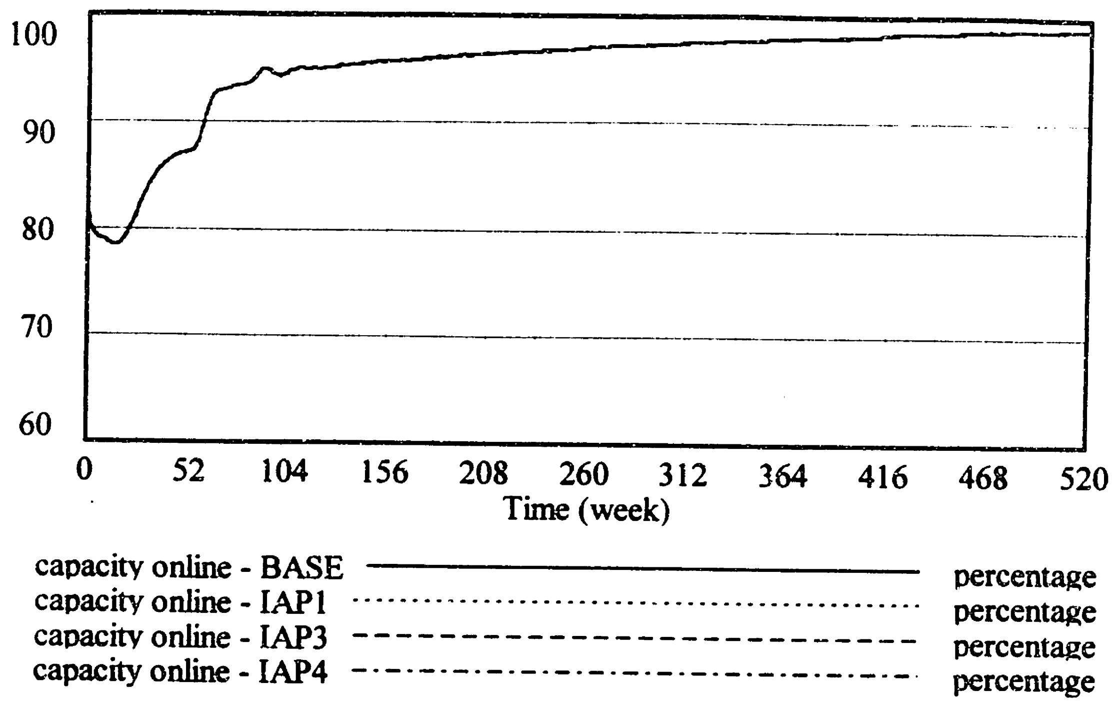


Variable 130



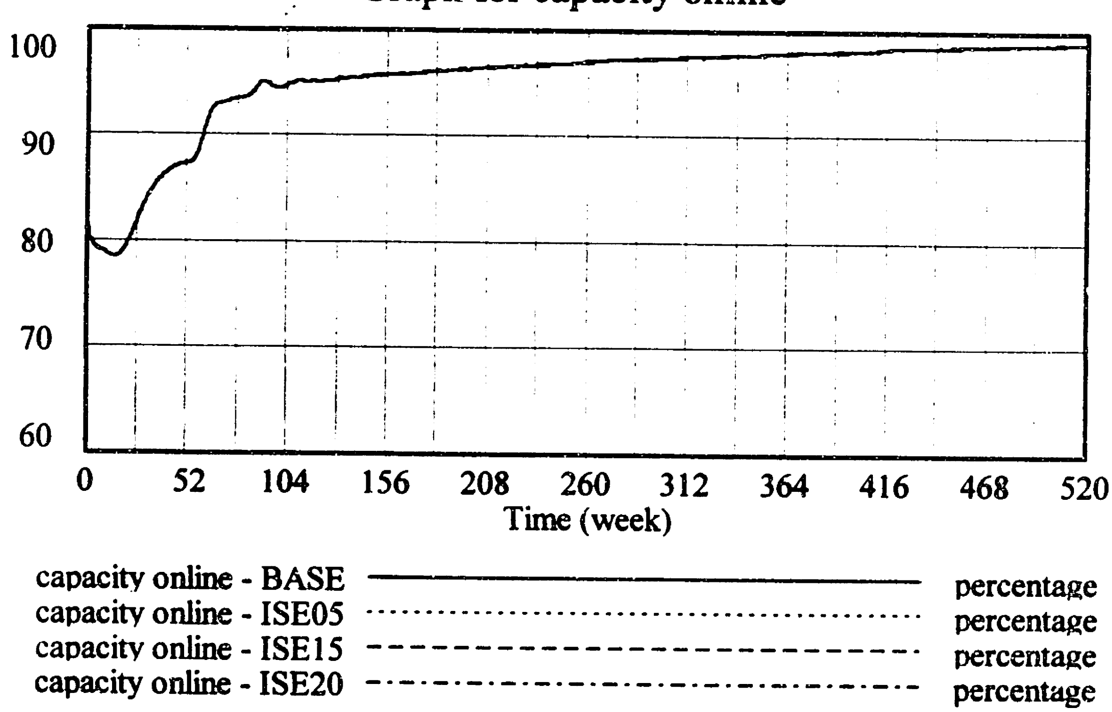
Variable 131

Graph for capacity online



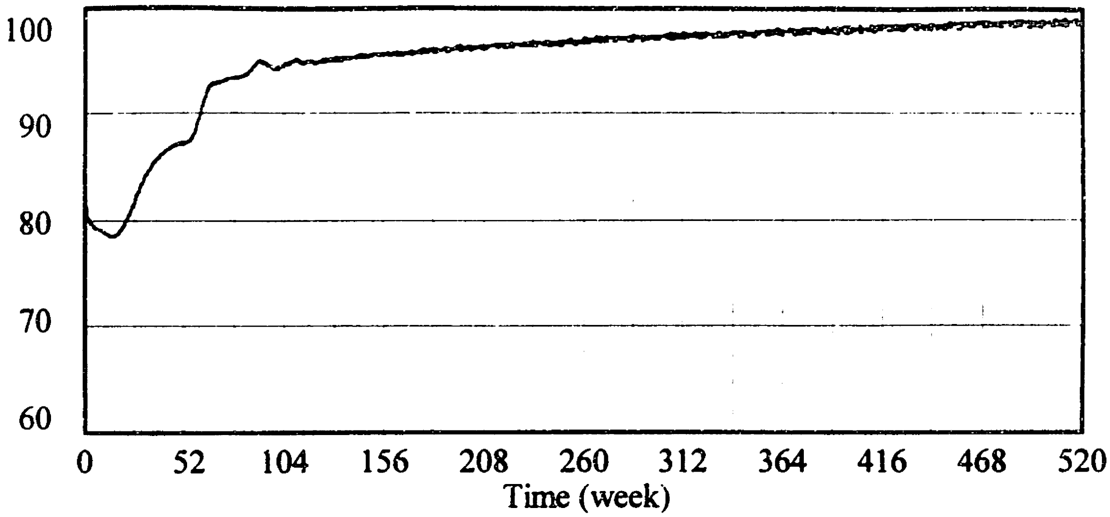
Variable 132

Graph for capacity online



Variable 133

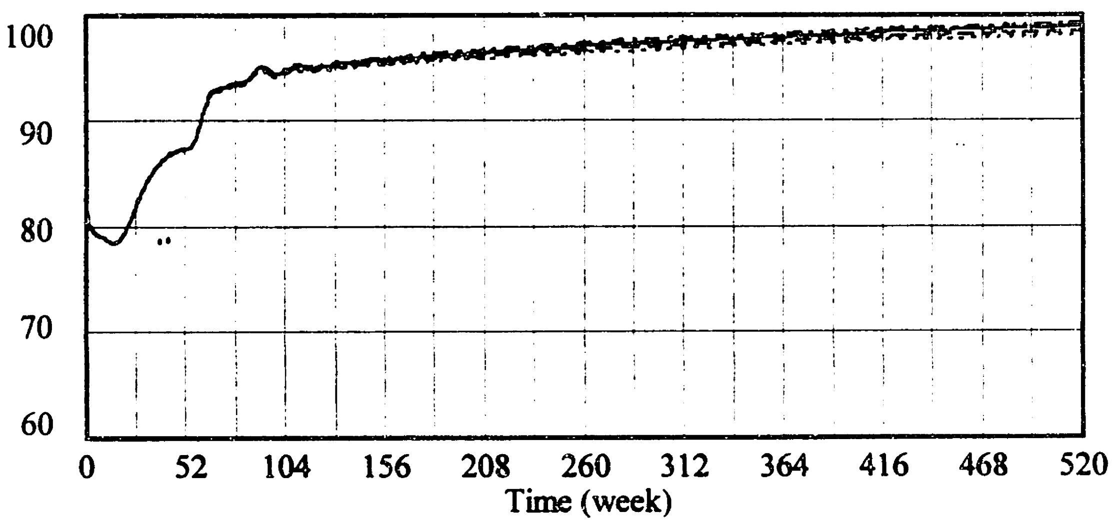
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - FQS03 ········ percentage
capacity online - FQS04 - - - - percentage
capacity online - FQS08 -·-·-·- percentage

Variable 134

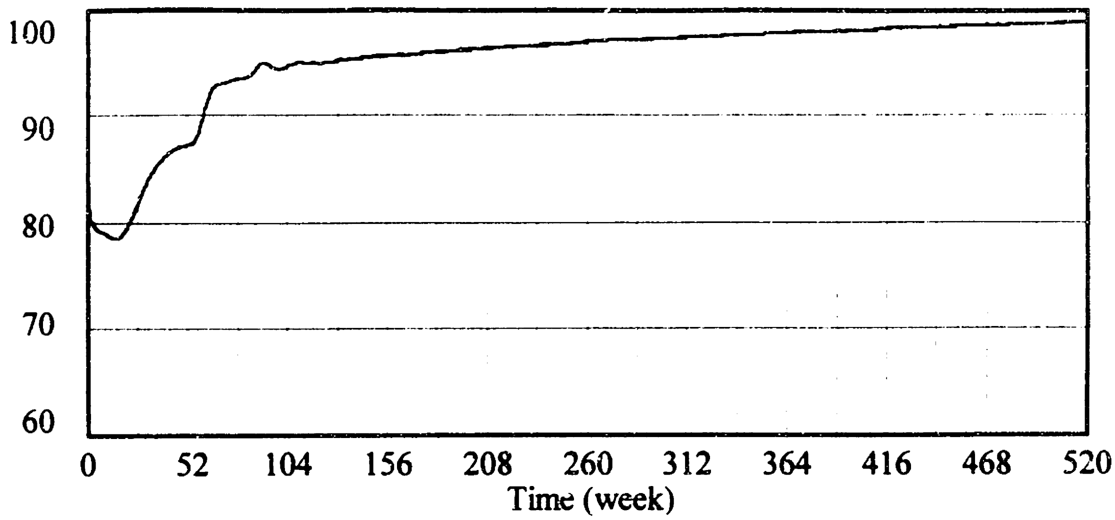
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - FSP03 ········ percentage
capacity online - FSP04 - - - - percentage
capacity online - FSP06 -·-·-·- percentage

Variable 135

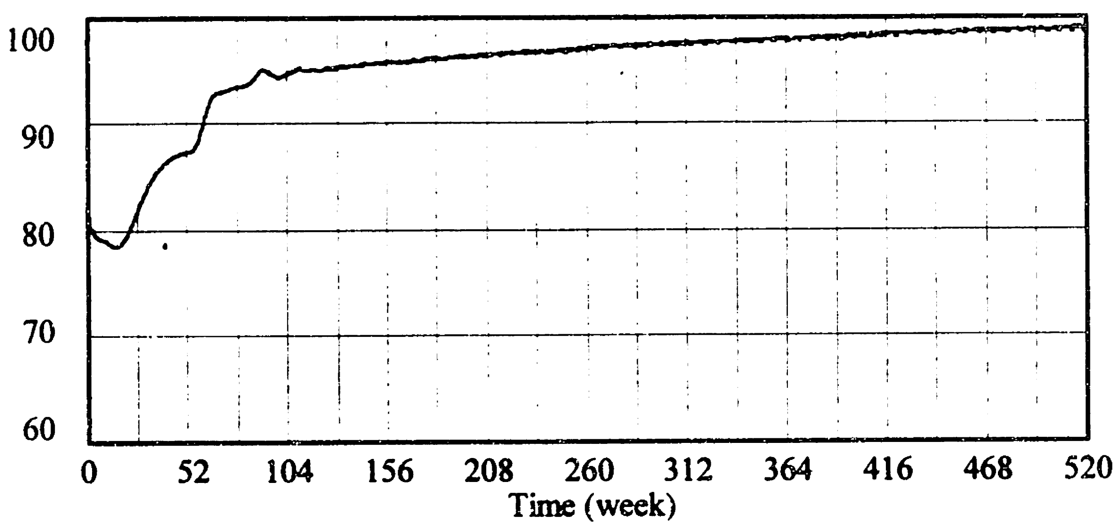
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - ITC3 ······ percentage
capacity online - ITC4 - - - - percentage
capacity online - ITC8 -·-·-· percentage

Variable 136

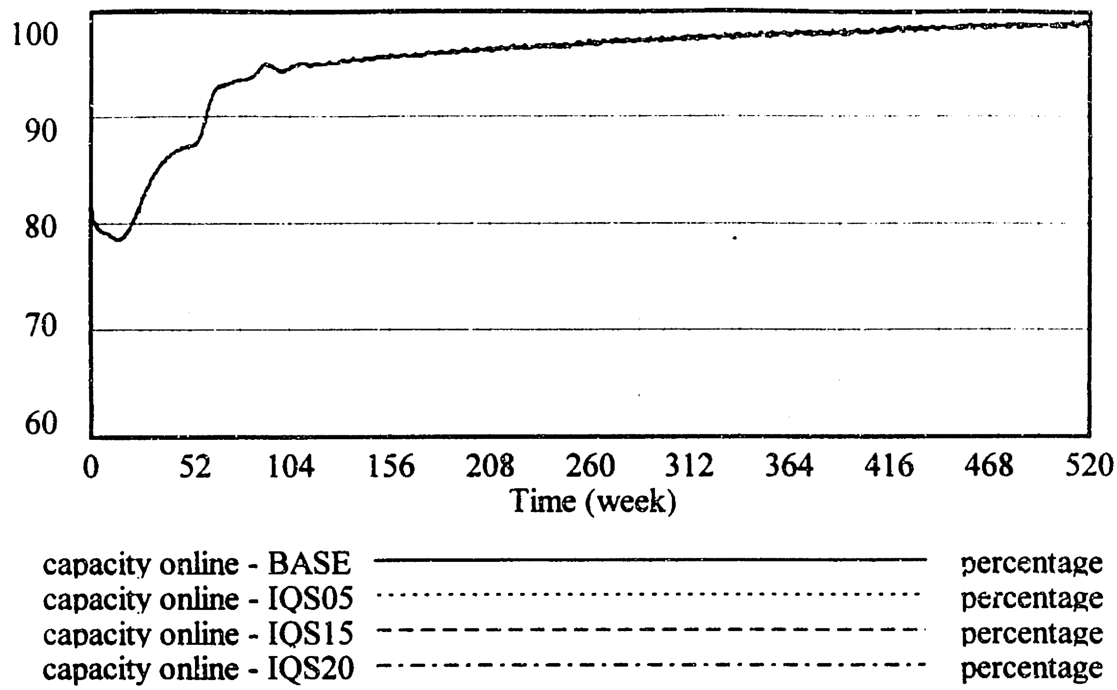
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - ITP1 ······ percentage
capacity online - ITP3 - - - - percentage
capacity online - ITP4 -·-·-· percentage

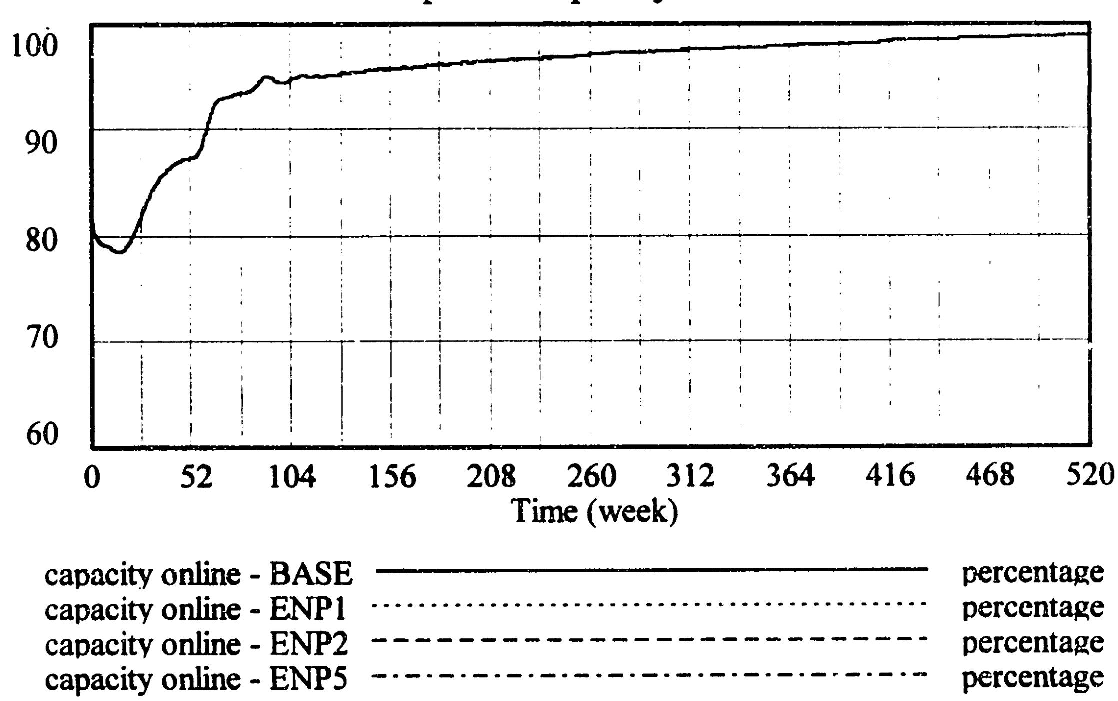
Variable 137

Graph for capacity online



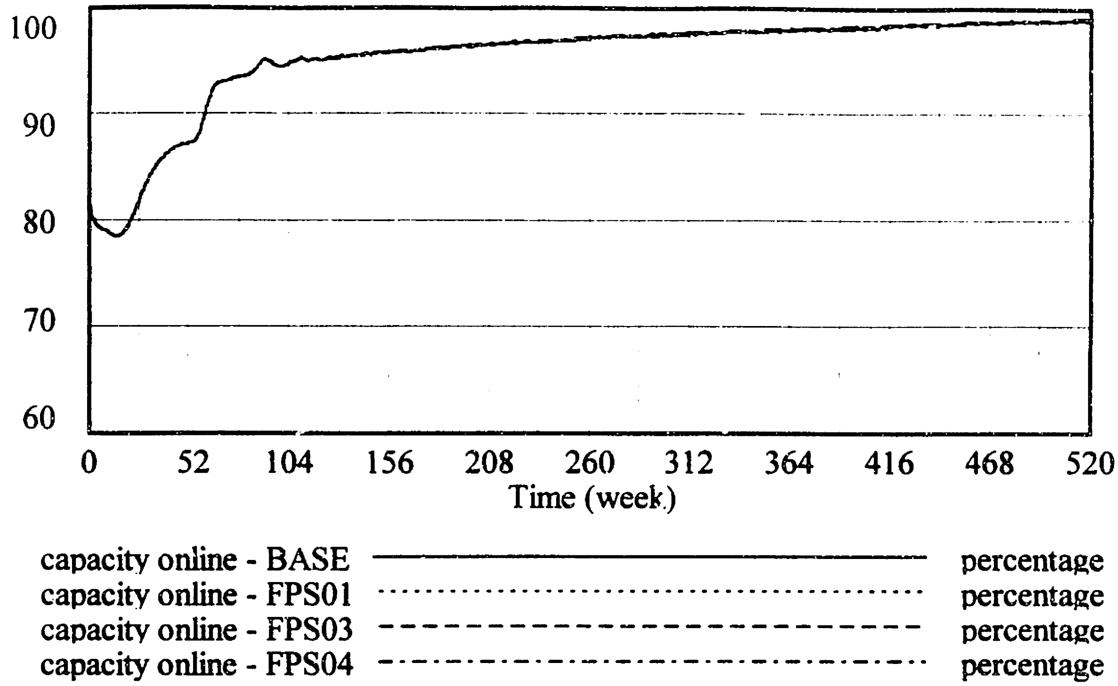
Variable 138

Graph for capacity online



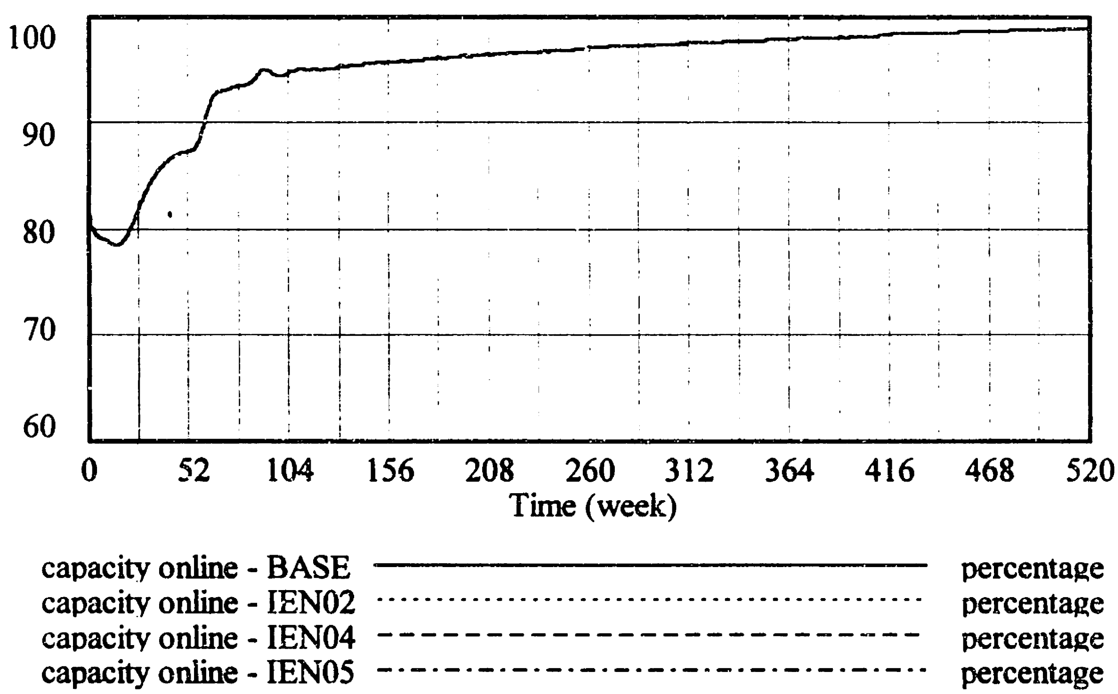
Variable 139

Graph for capacity online

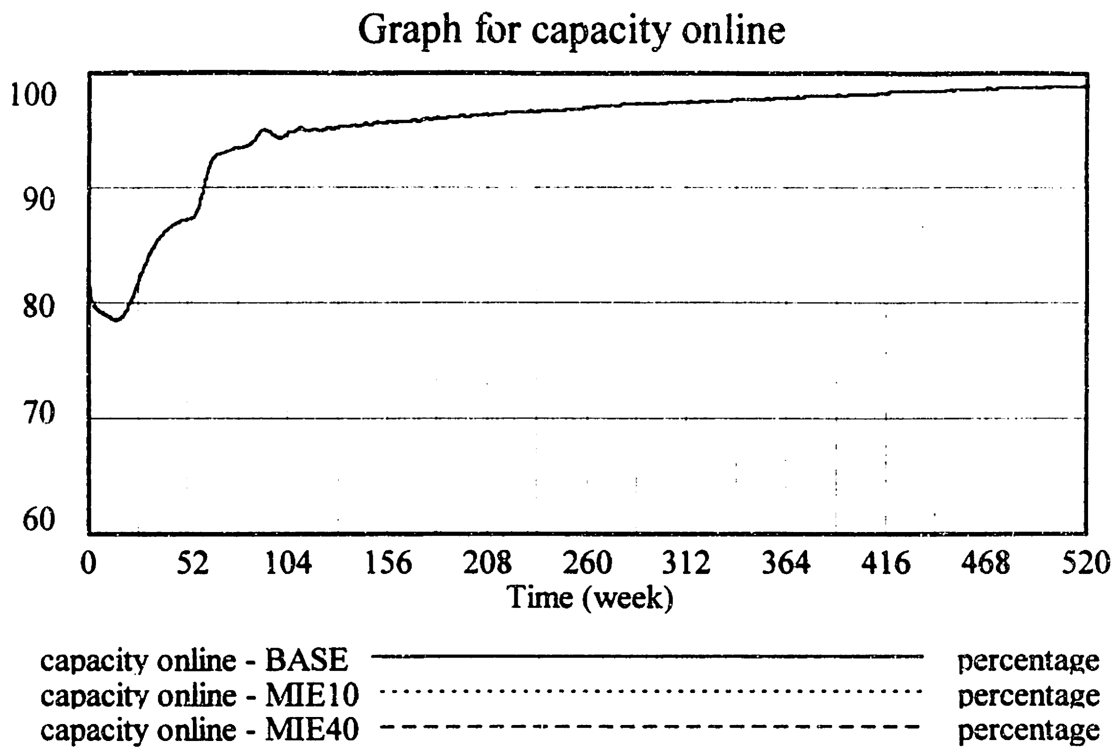


Variable 140

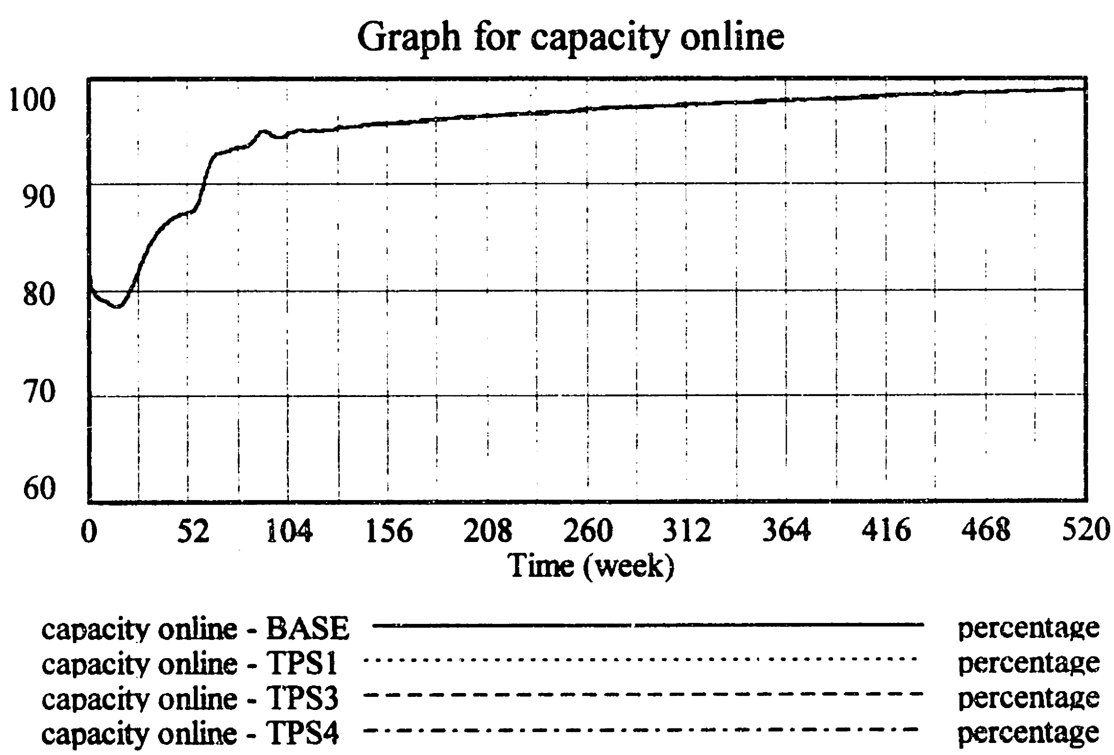
Graph for capacity online



Variable 141

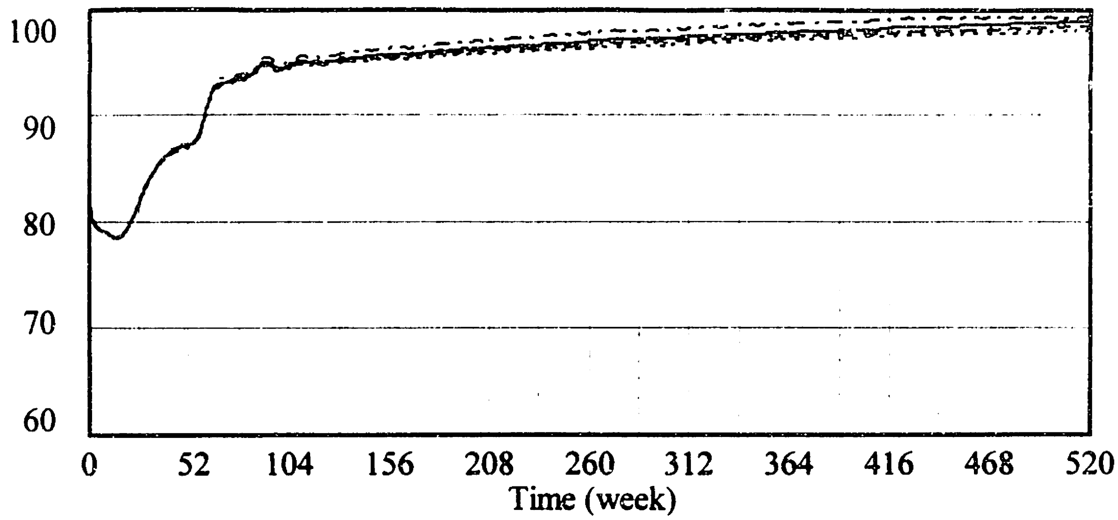


Variable 142



Variable 143

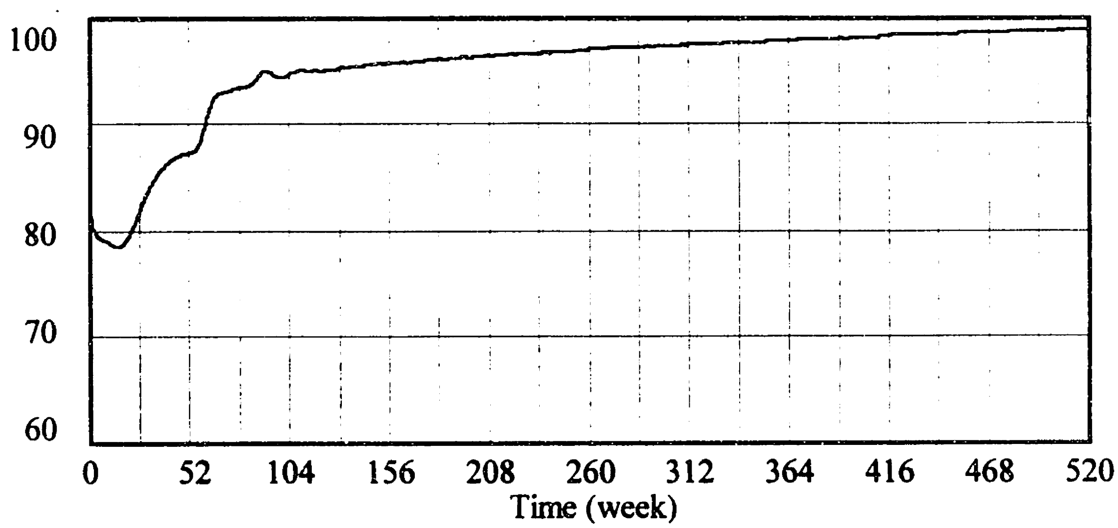
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - CPS3 ········ percentage
capacity online - CPS4 - - - - percentage
capacity online - CPS8 -·-·-·- percentage

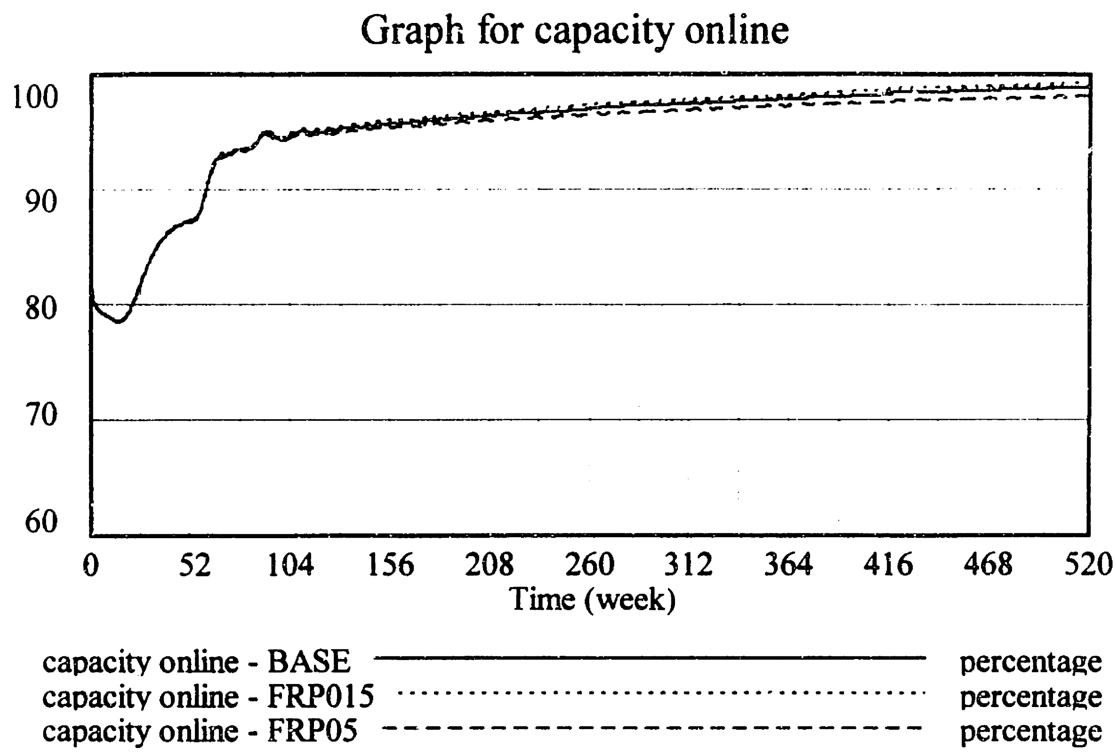
Variable 144

Graph for capacity online

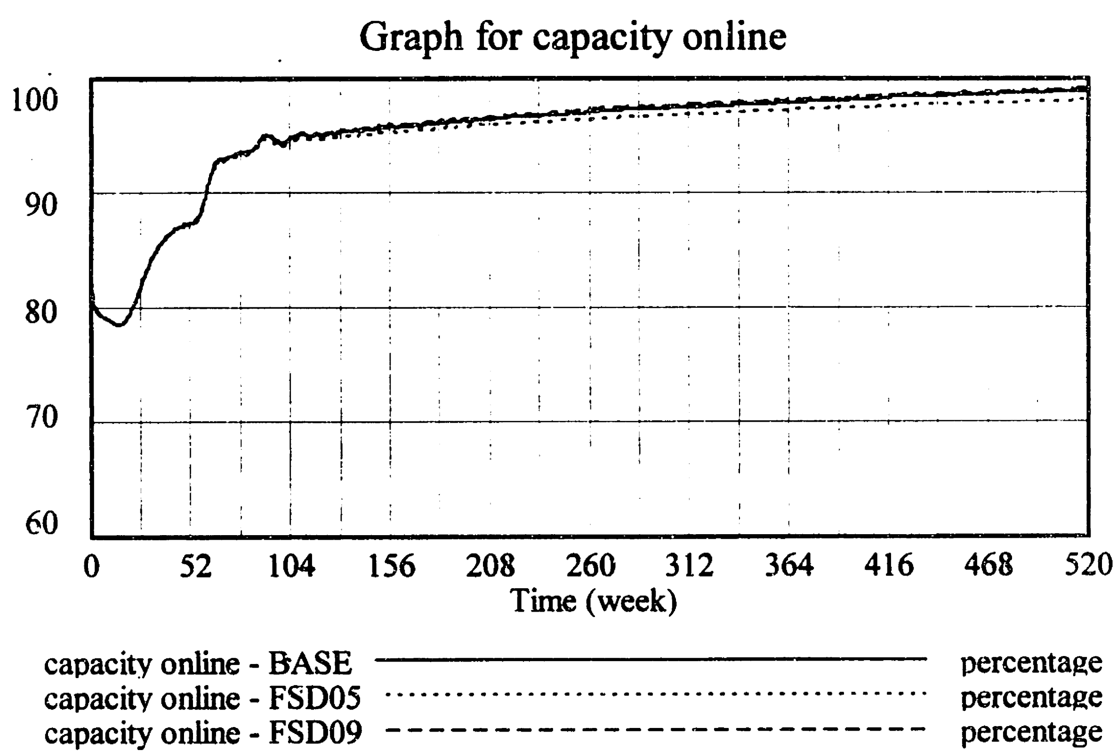


capacity online - BASE ———— percentage
capacity online - FRA02 ········ percentage
capacity online - FRA03 - - - - percentage
capacity online - FRA05 -·-·-·- percentage

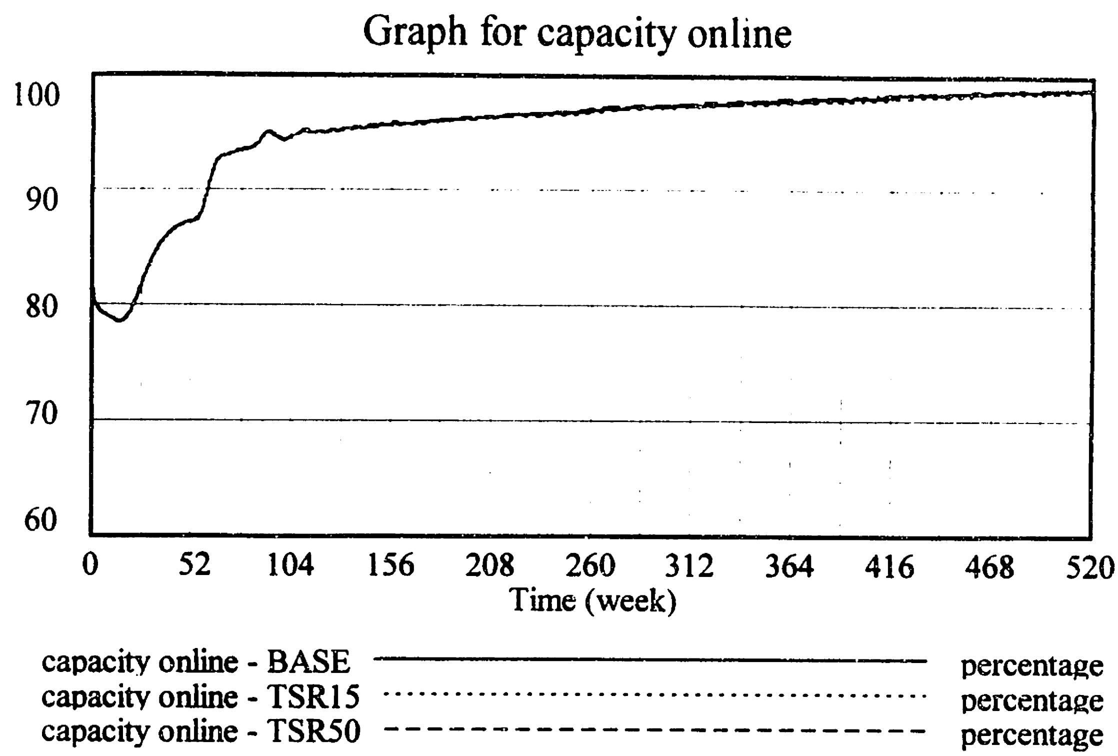
Variable 145



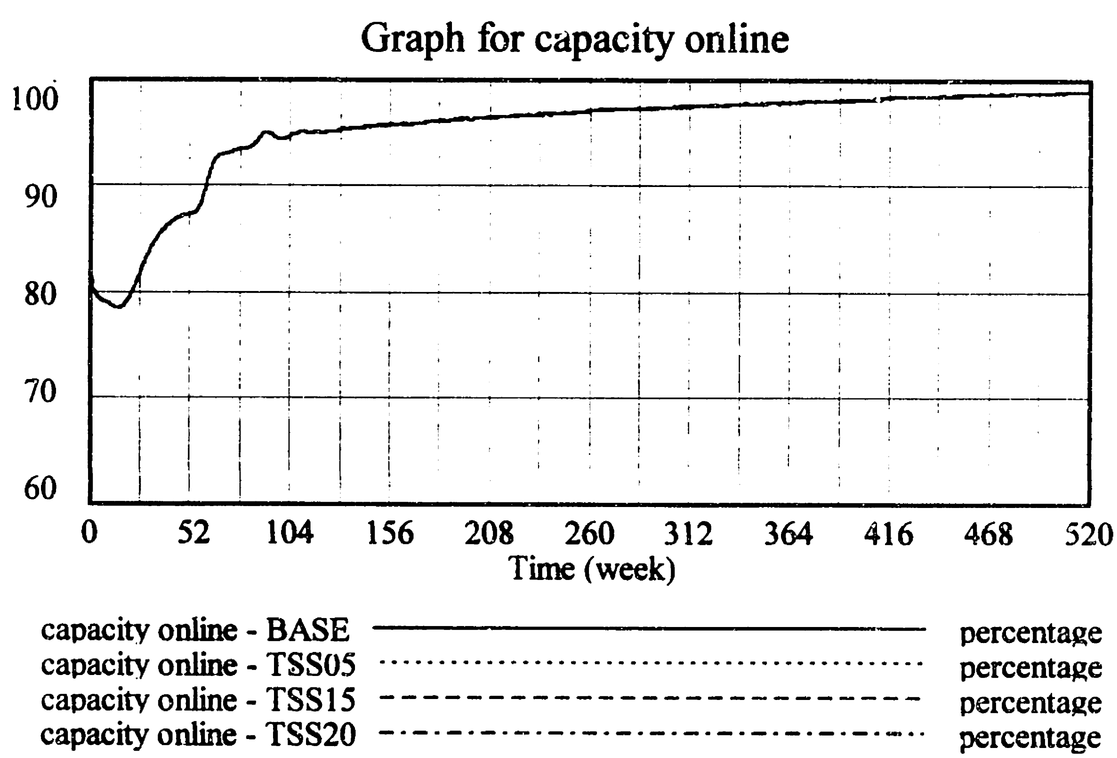
Variable 146



Variable 147

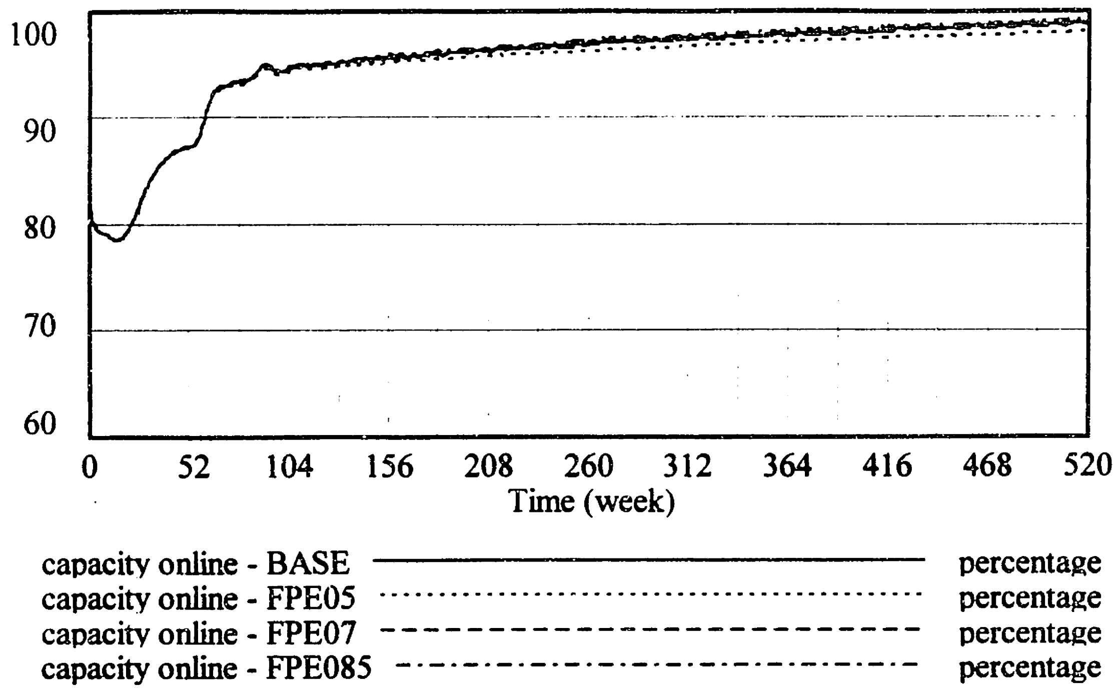


Variable 148



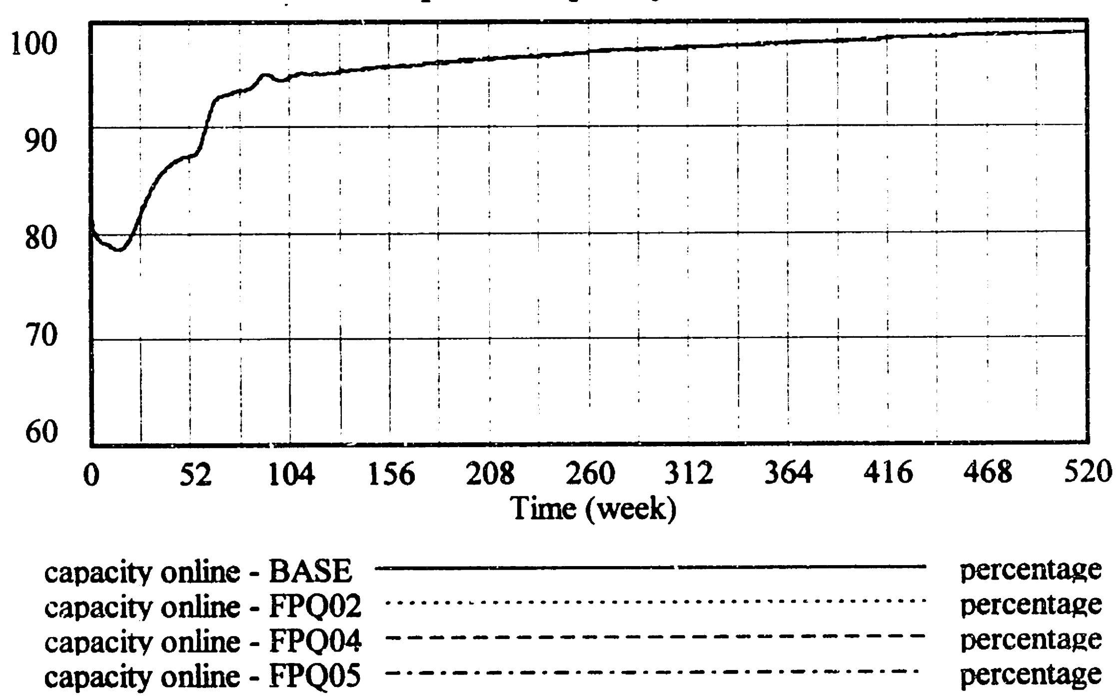
Variable 149

Graph for capacity online

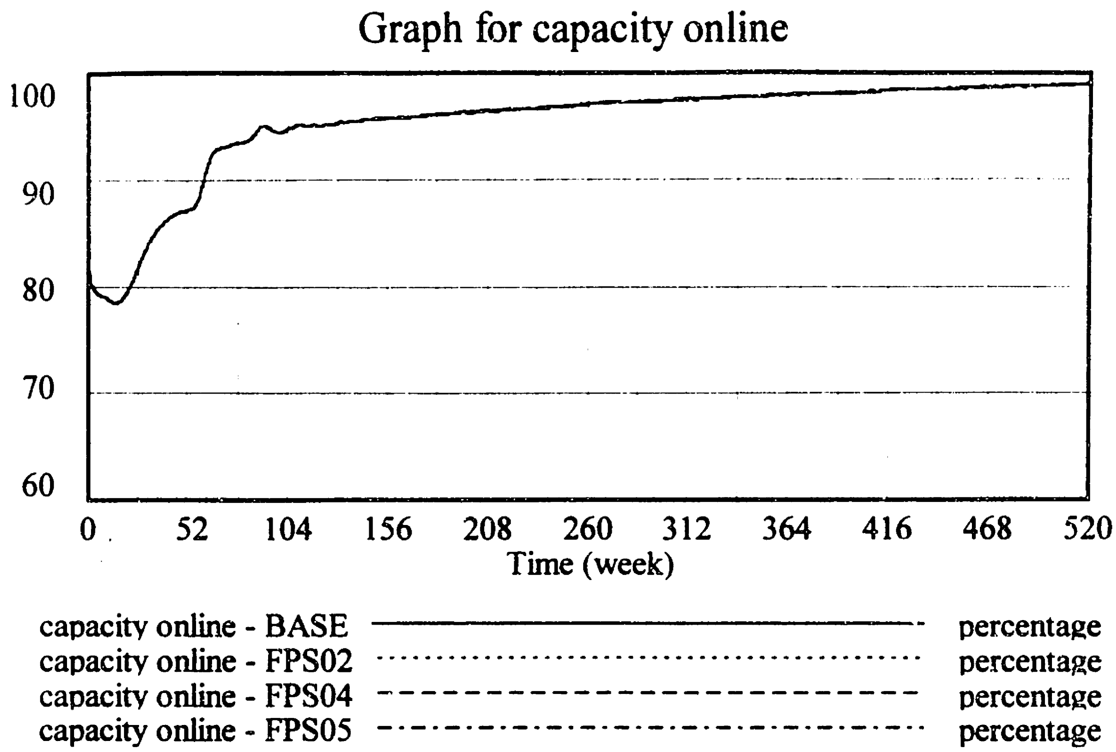


Variable 150

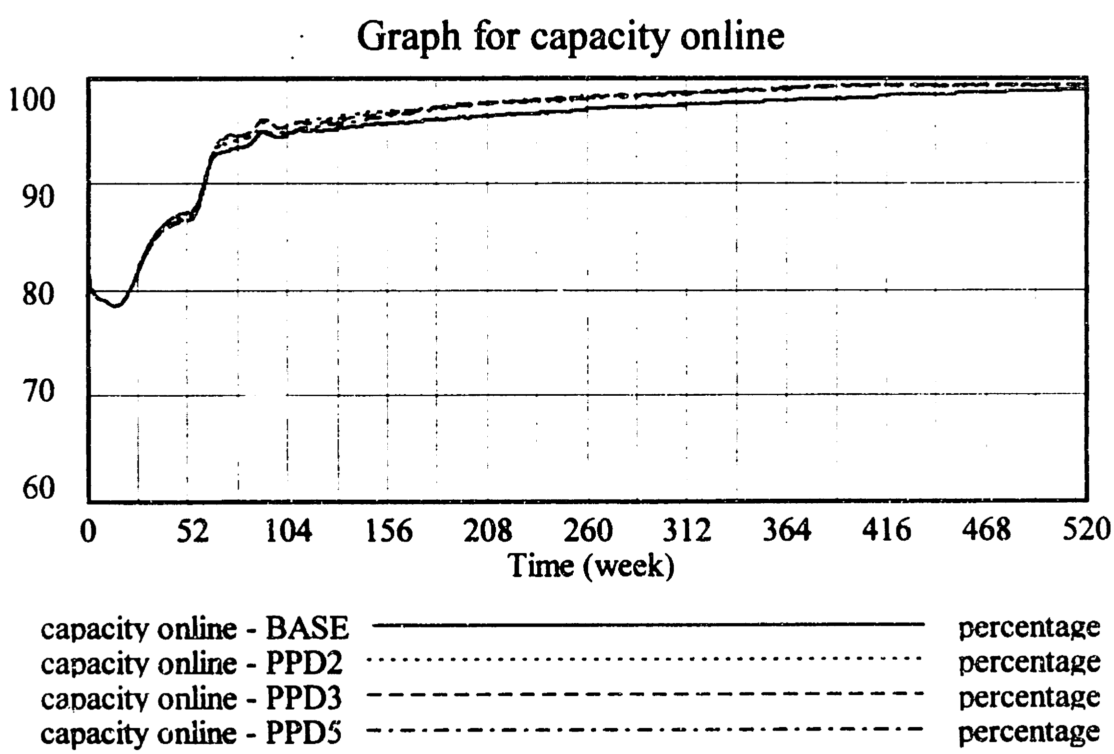
Graph for capacity online



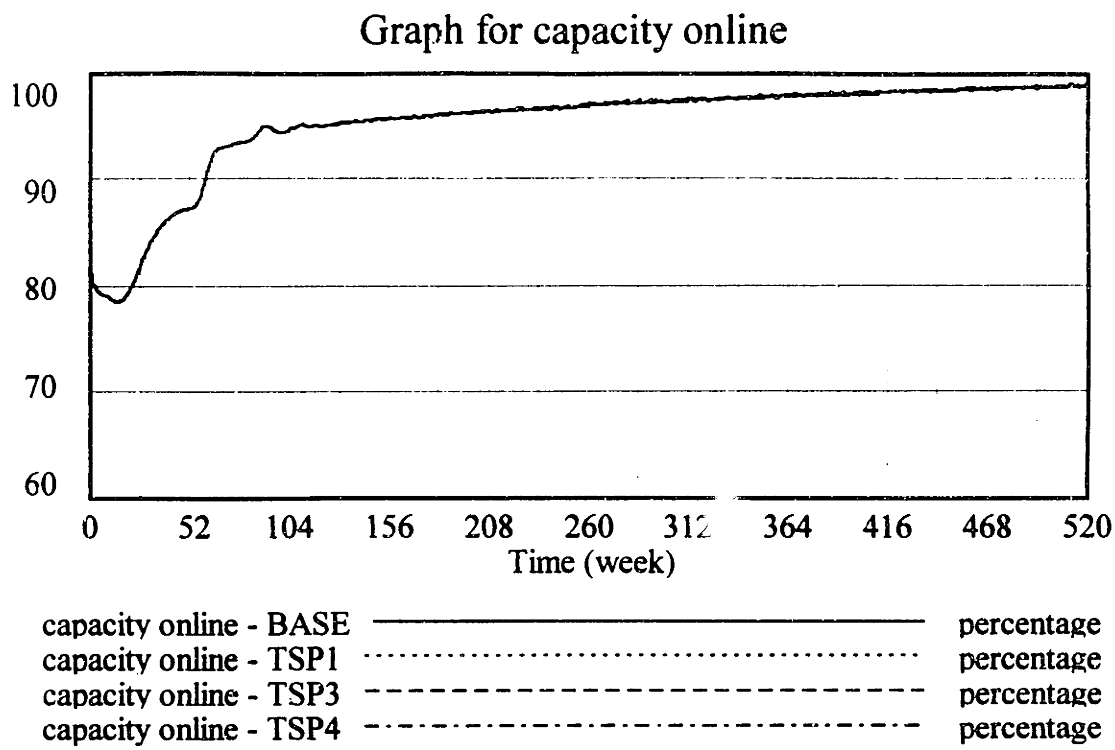
Variable 151



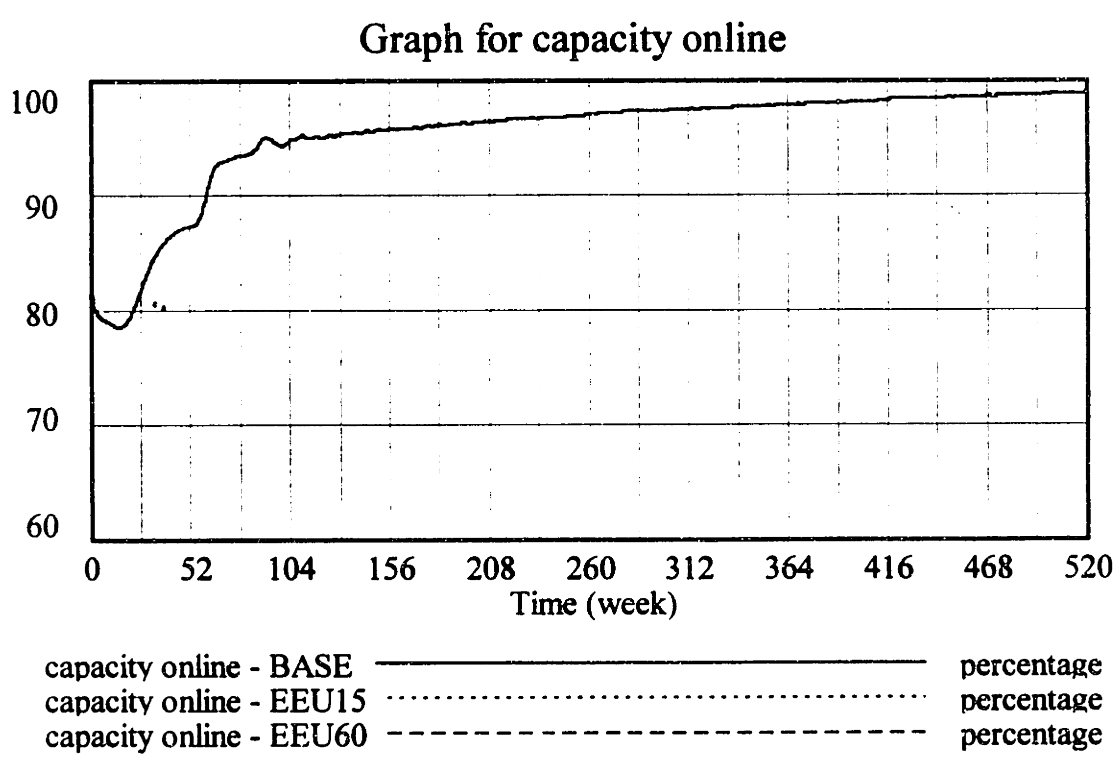
Variable 152



Variable 153

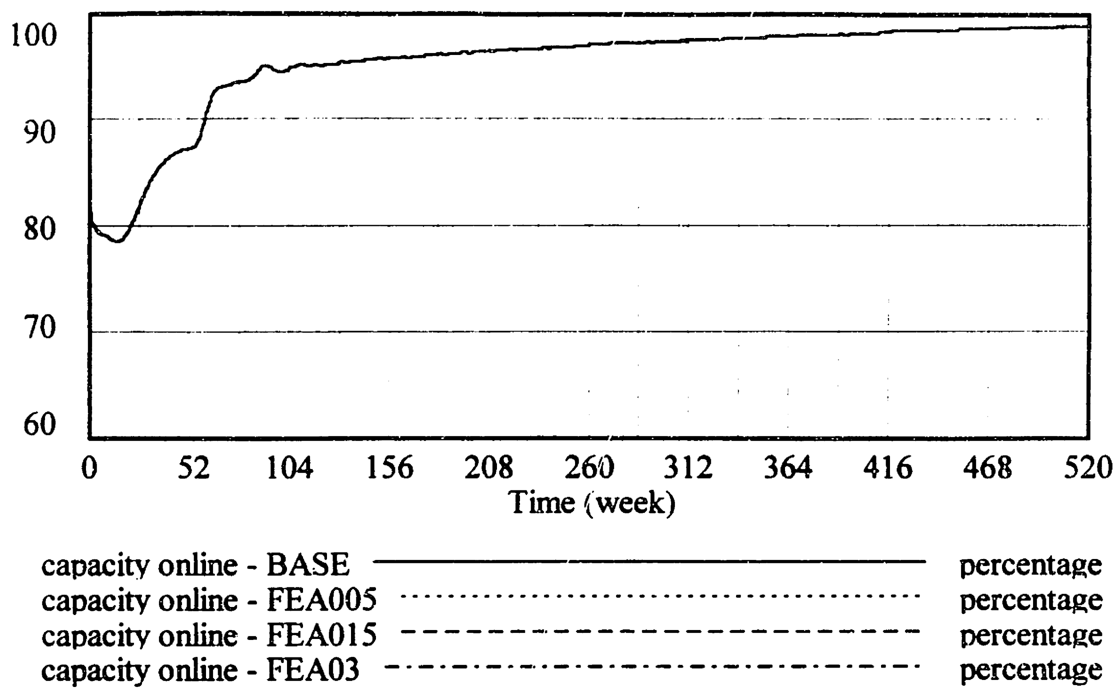


Variable 154



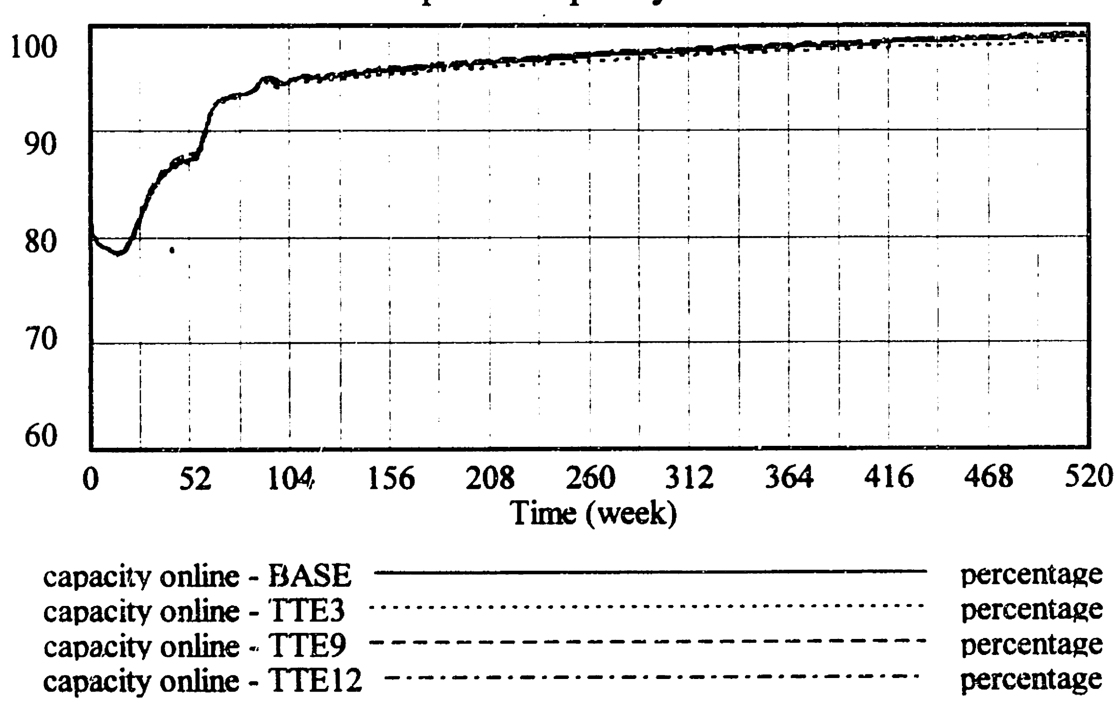
Variable 155

Graph for capacity online



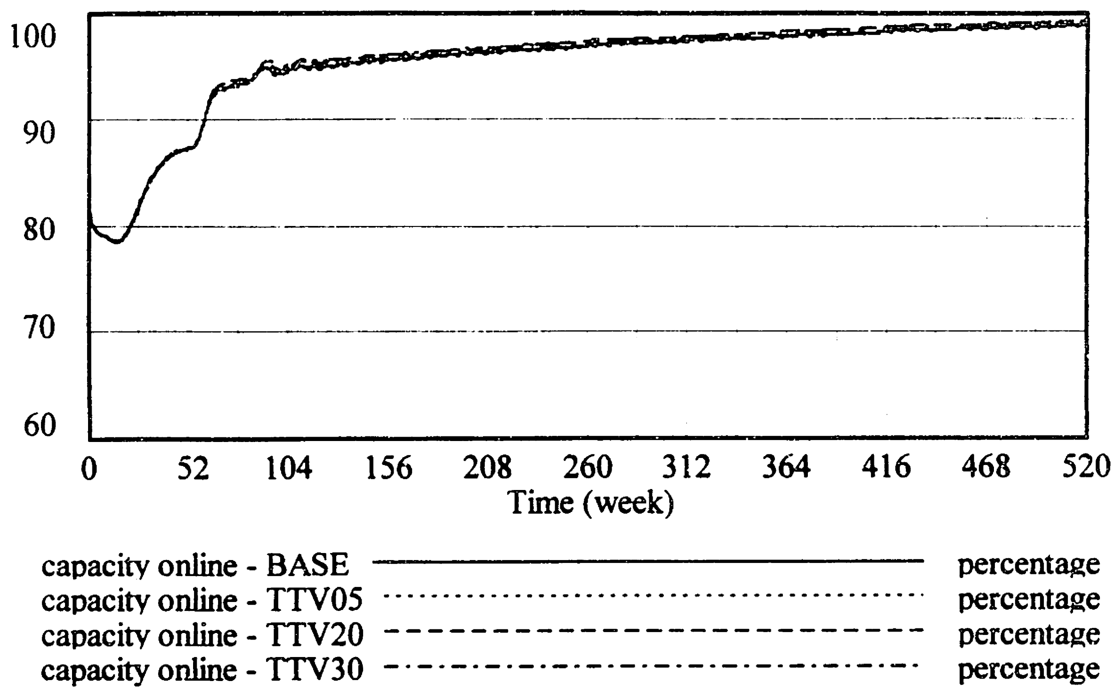
Variable 156

Graph for capacity online



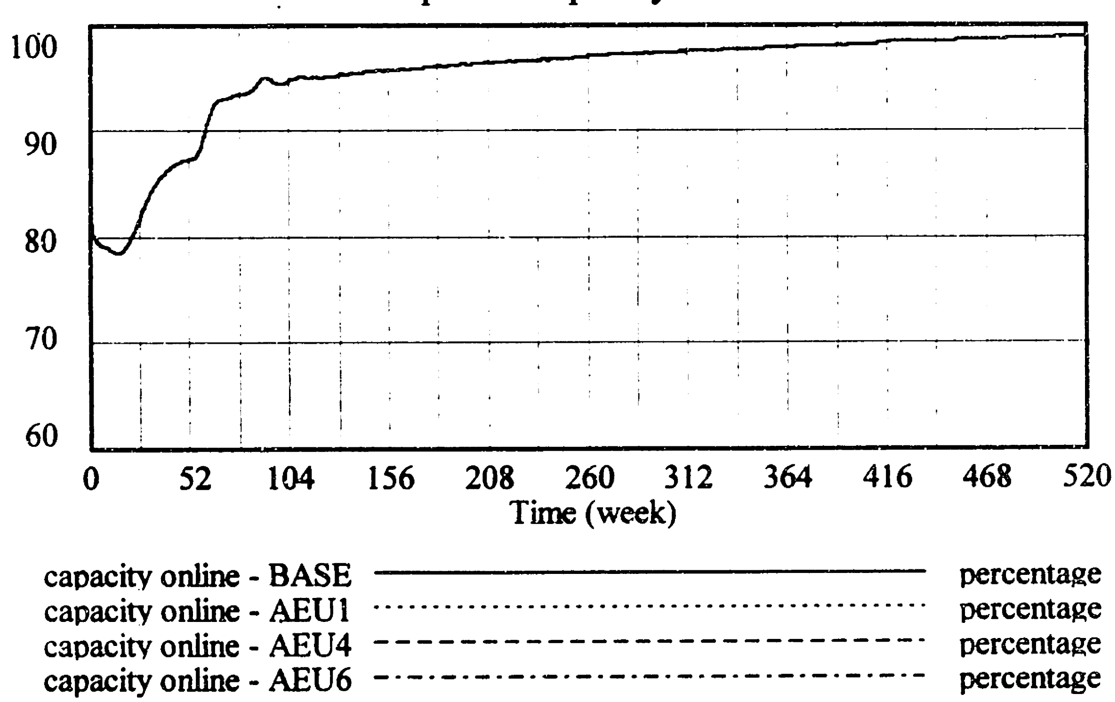
Variable 157

Graph for capacity online



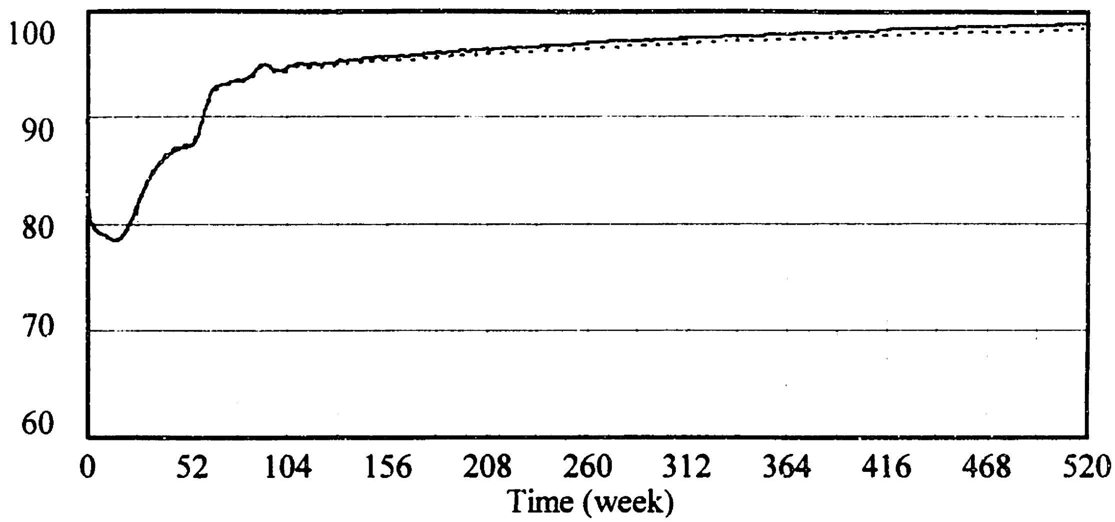
Variable 158

Graph for capacity online



Variable 159

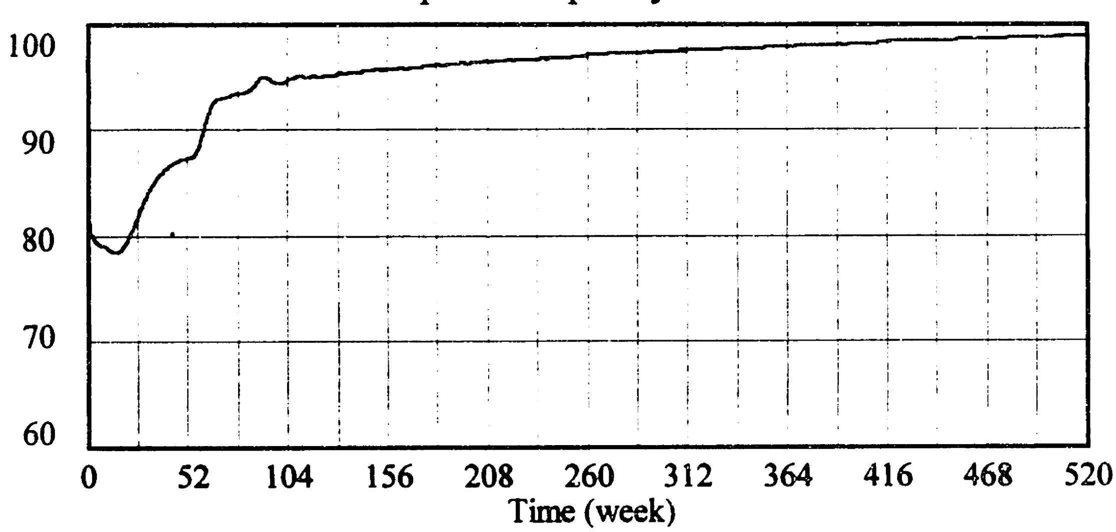
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - AMU1 ········ percentage
capacity online - AMU3 - - - - percentage
capacity online - AMU5 -·-·-·- percentage

Variable 160

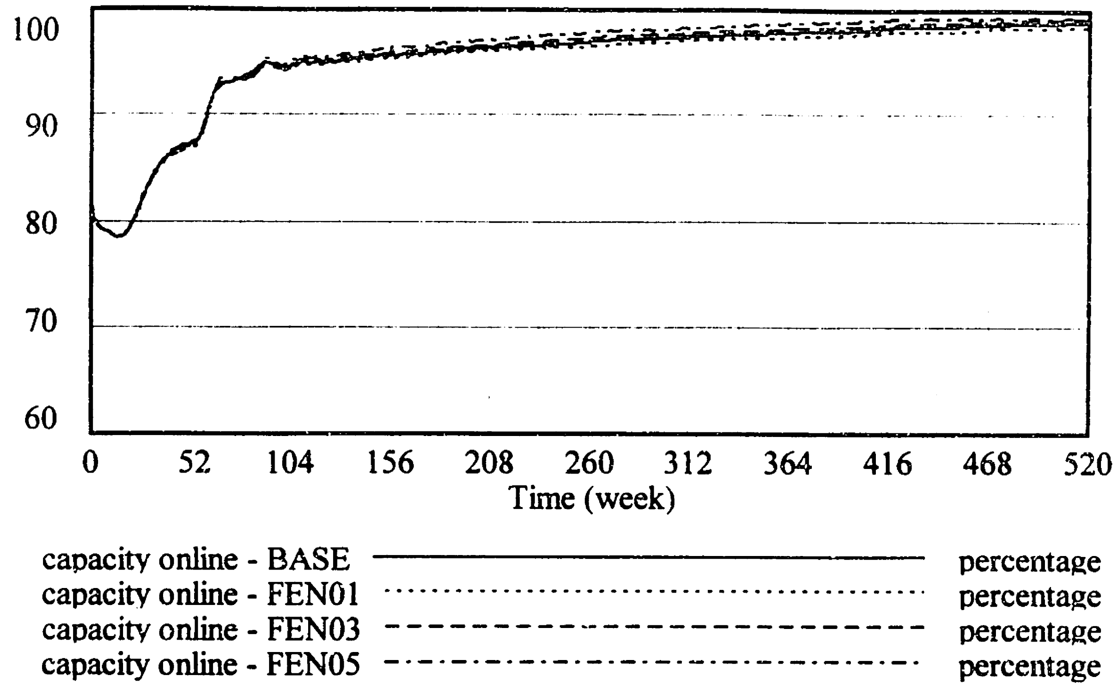
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - FCA01 ········ percentage
capacity online - FCA03 - - - - percentage
capacity online - FCA05 -·-·-·- percentage

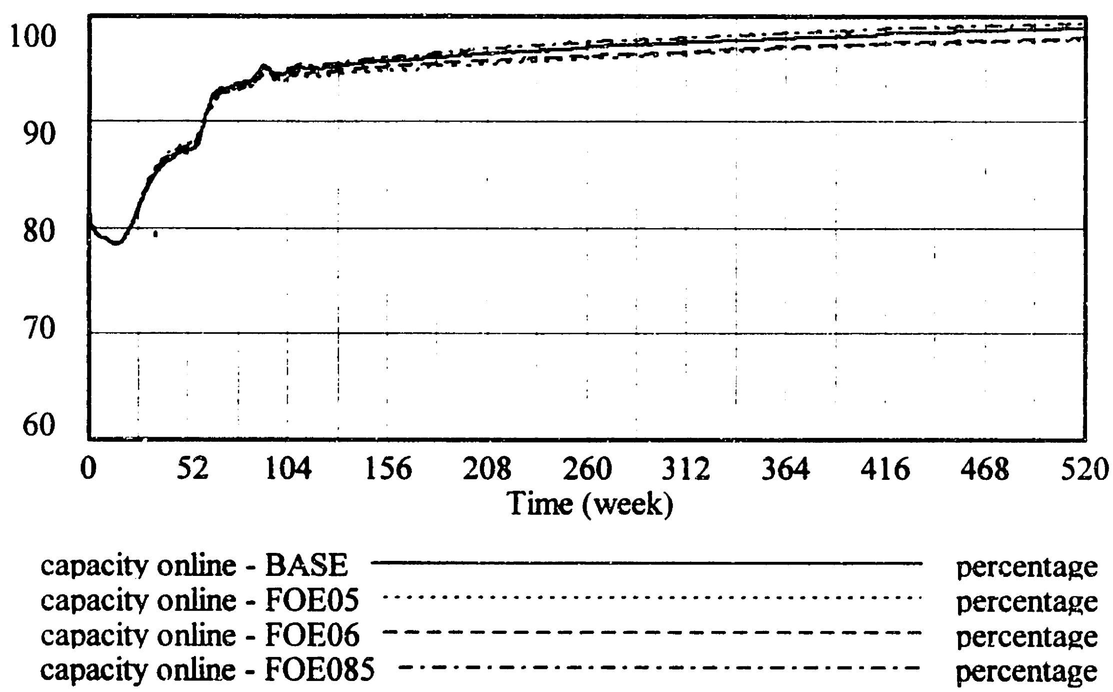
Variable 161

Graph for capacity online



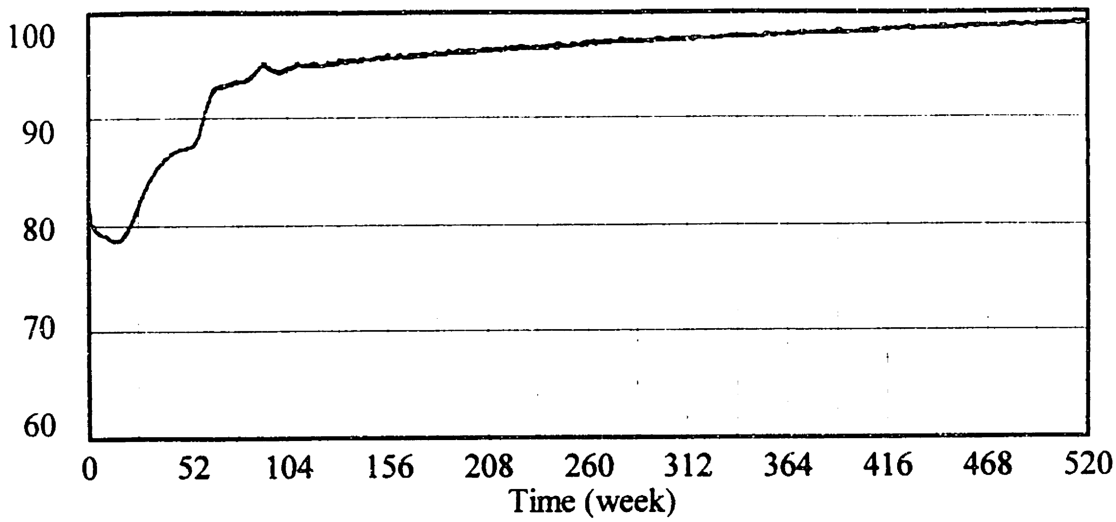
Variable 162

Graph for capacity online



Variable 163

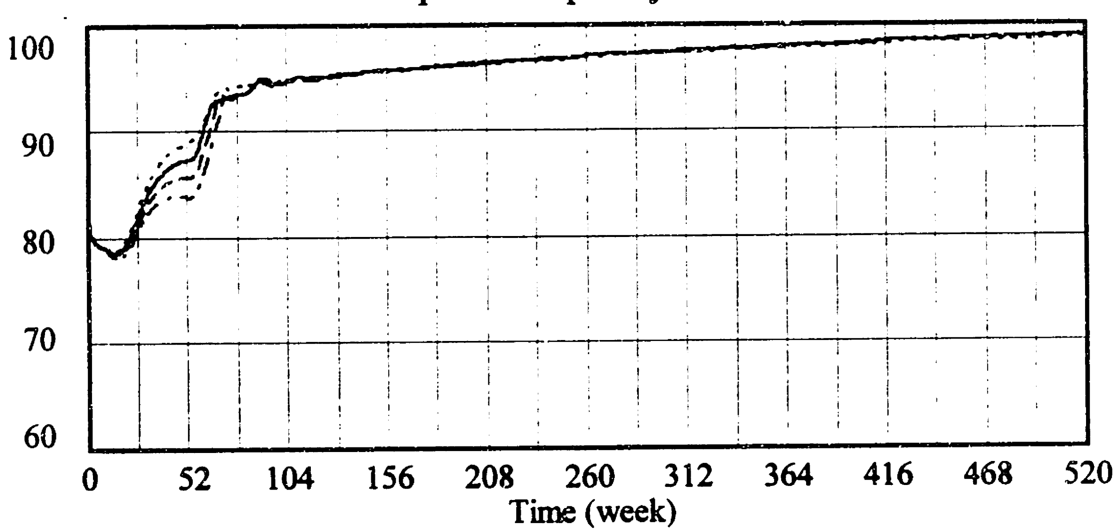
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - TTA05 ········ percentage
capacity online - TTA15 - - - - - percentage
capacity online - TTA20 -·-·-·-· percentage

Variable 164

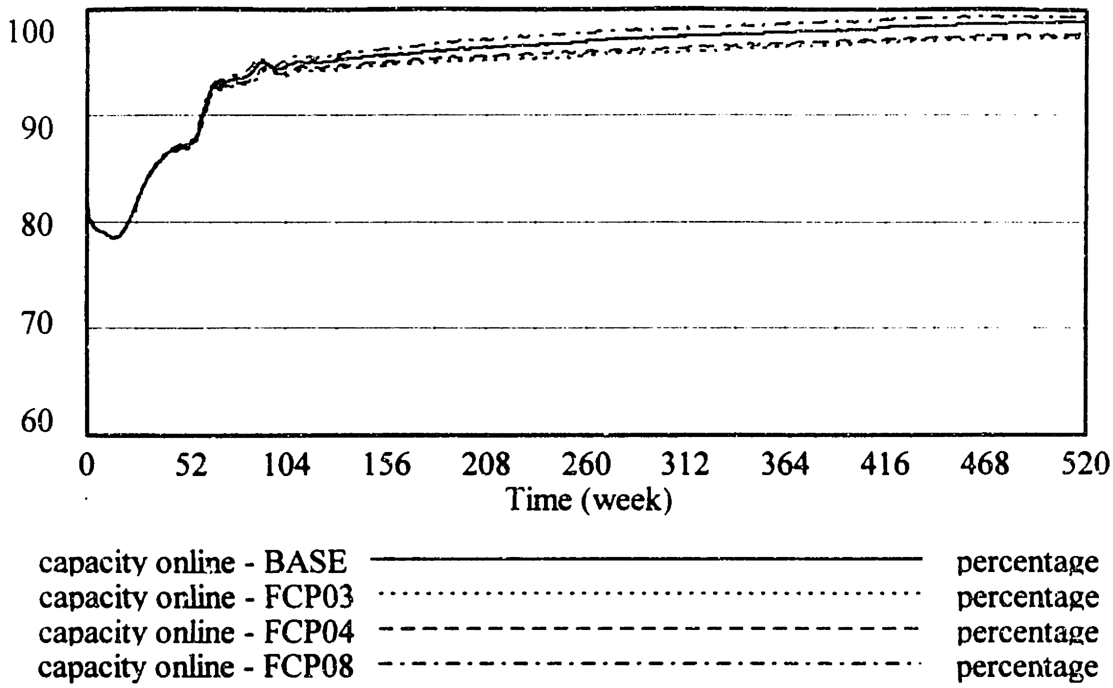
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - FCM01 ········ percentage
capacity online - FCM03 - - - - - percentage
capacity online - FCM04 -·-·-·-· percentage

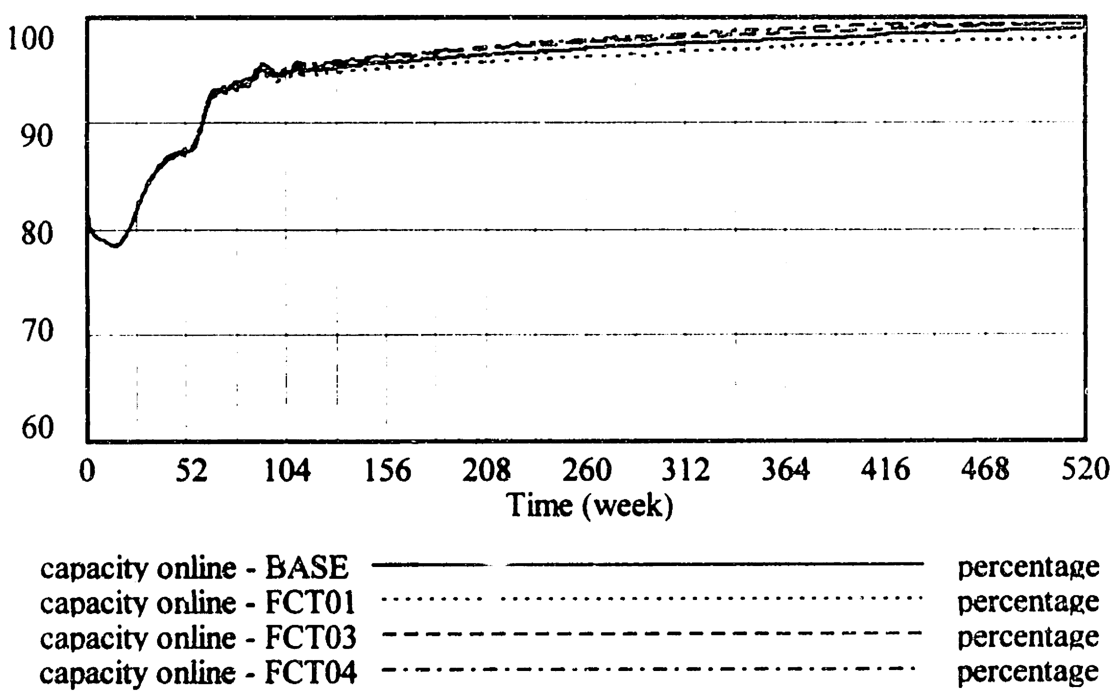
Variable 165

Graph for capacity online

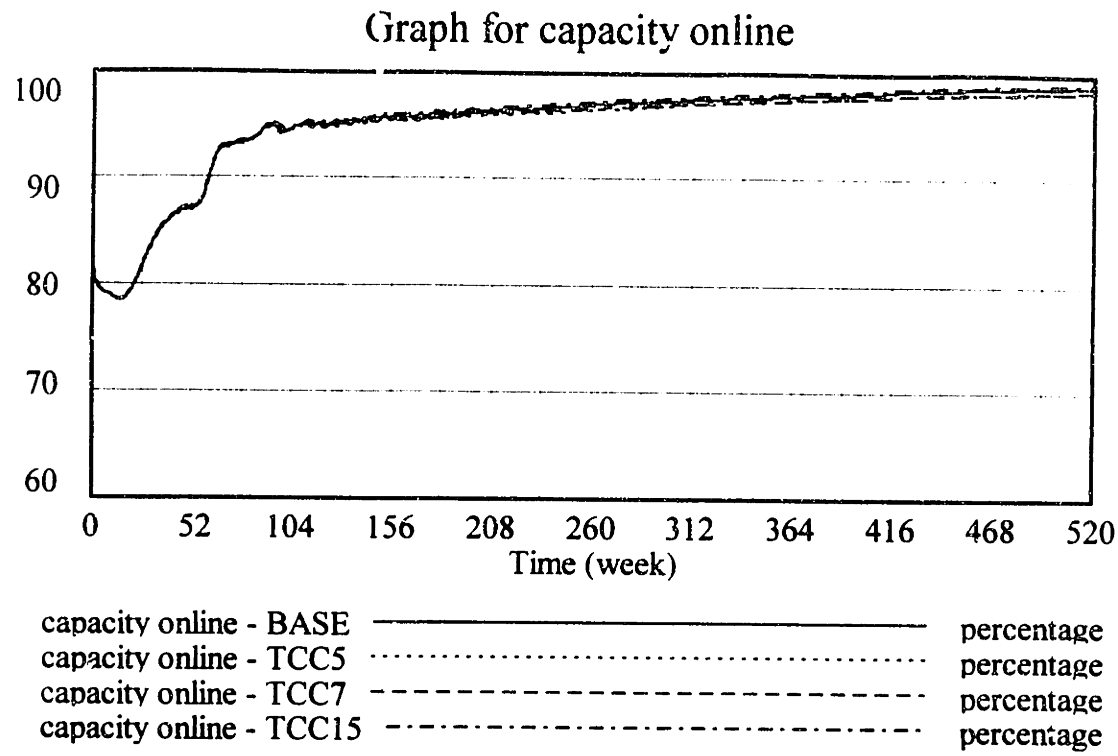


Variable 166

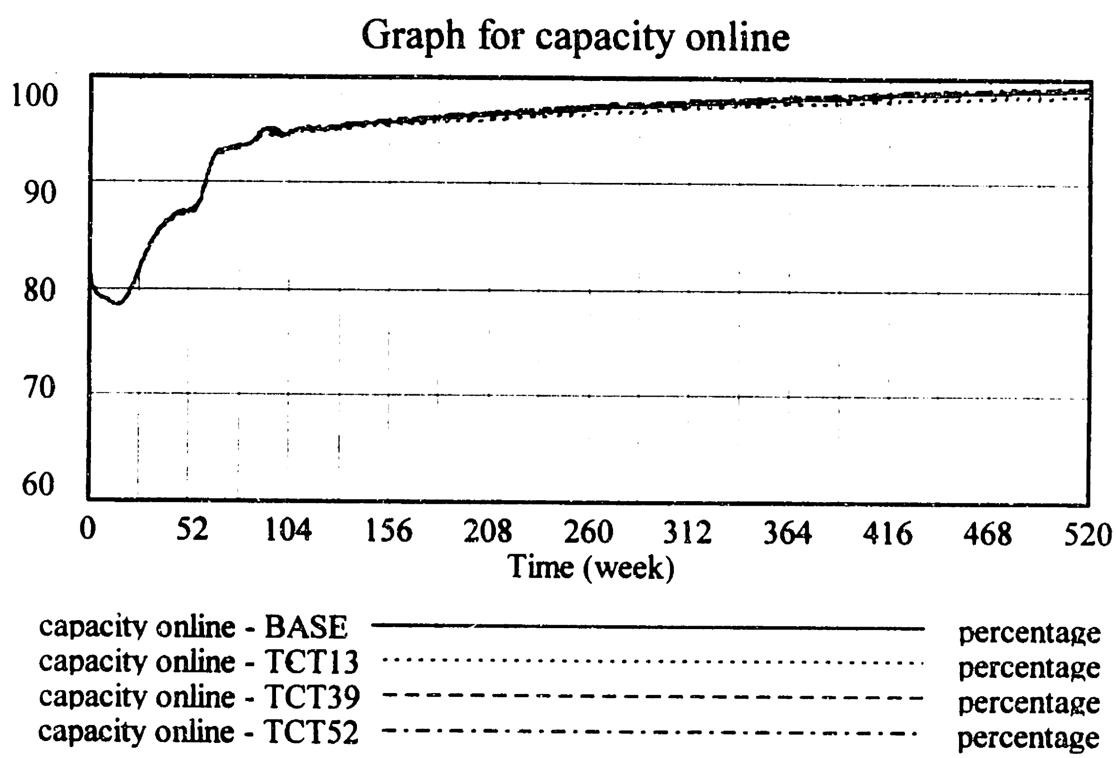
Graph for capacity online



Variable 167

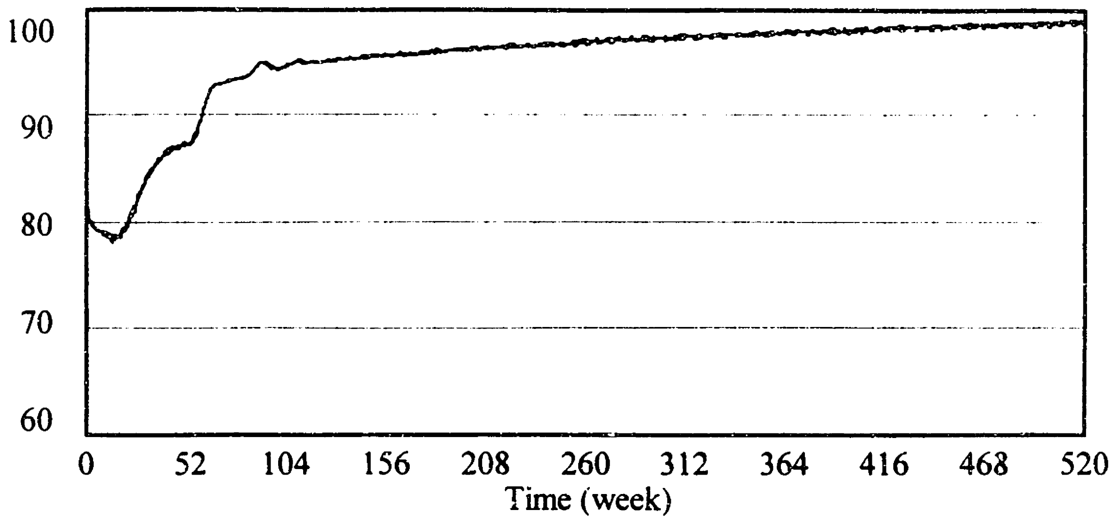


Variable 168



Variable 169

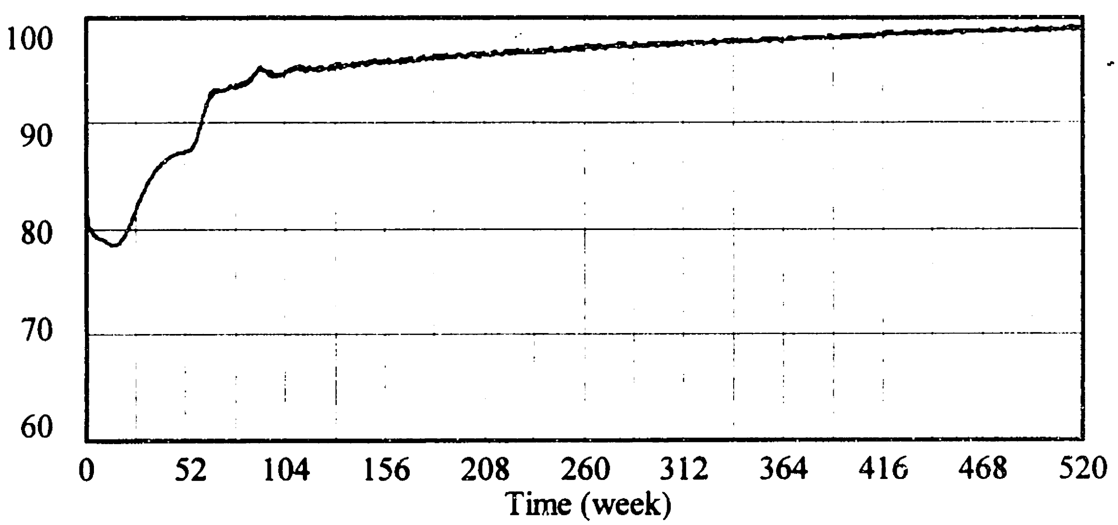
Graph for capacity online



capacity online - BASE ———————— percentage
capacity online - TPM6 ··········· percentage
capacity online - TPM9 - - - - - - - - percentage
capacity online - TPM18 -·-·-·-·-·-· percentage

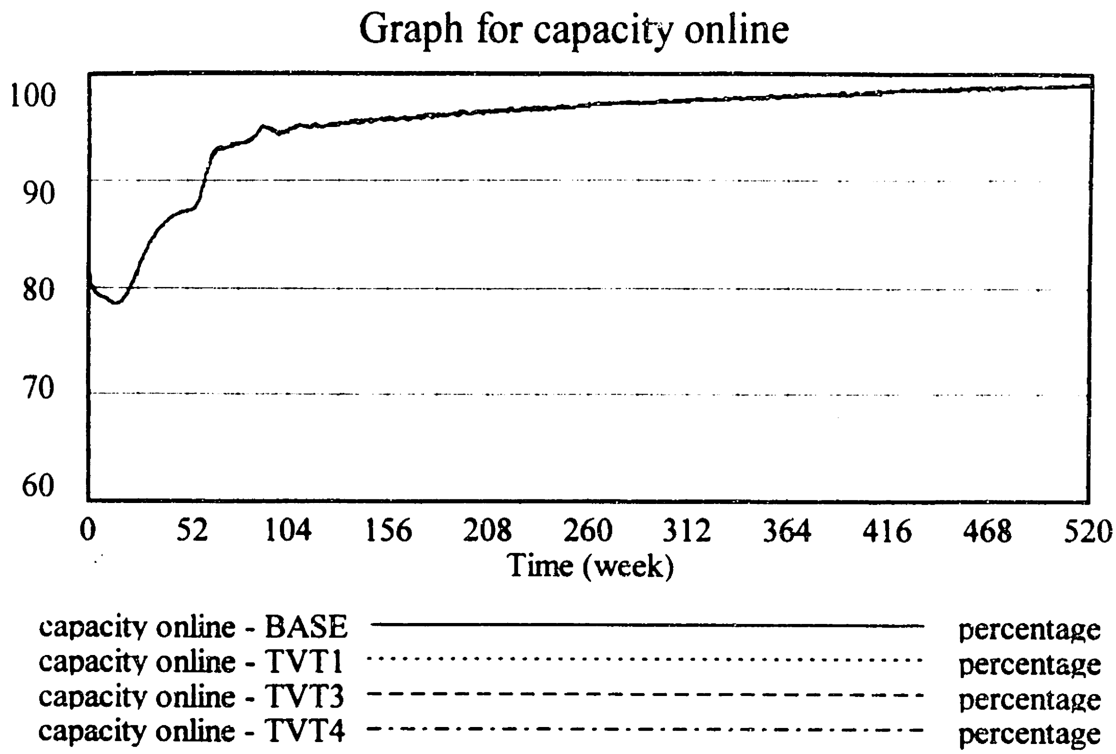
Variable 170

Graph for capacity online

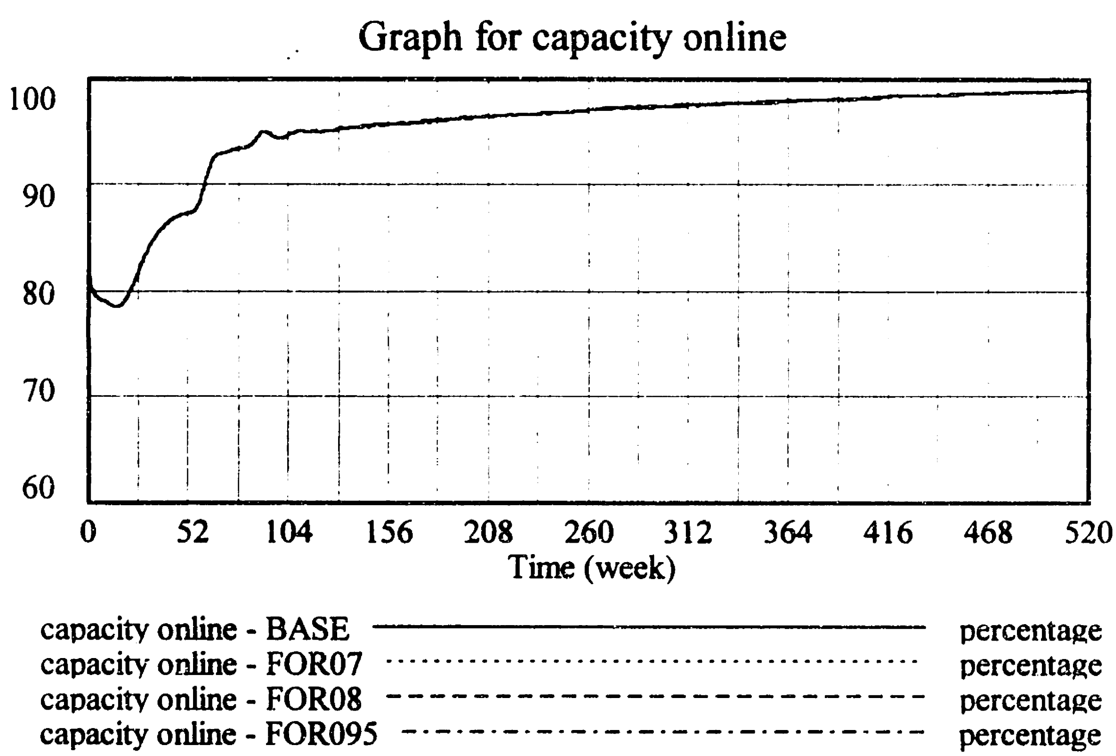


capacity online - BASE ———————— percentage
capacity online - TVP05 ··········· percentage
capacity online - TVP15 - - - - - - - - percentage
capacity online - TVP20 -·-·-·-·-·-· percentage

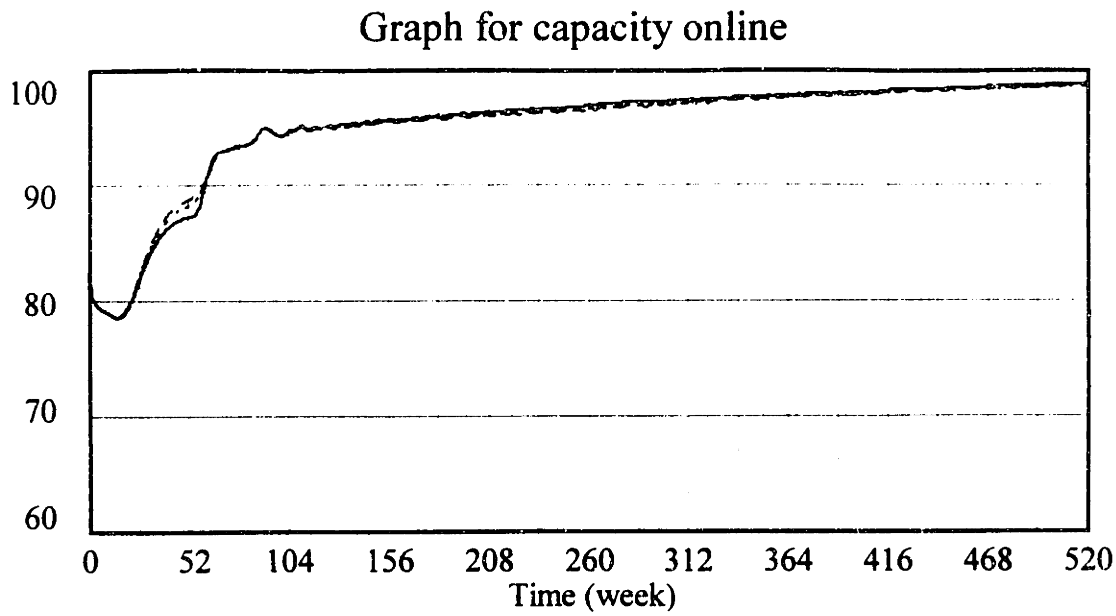
Variable 171



Variable 172

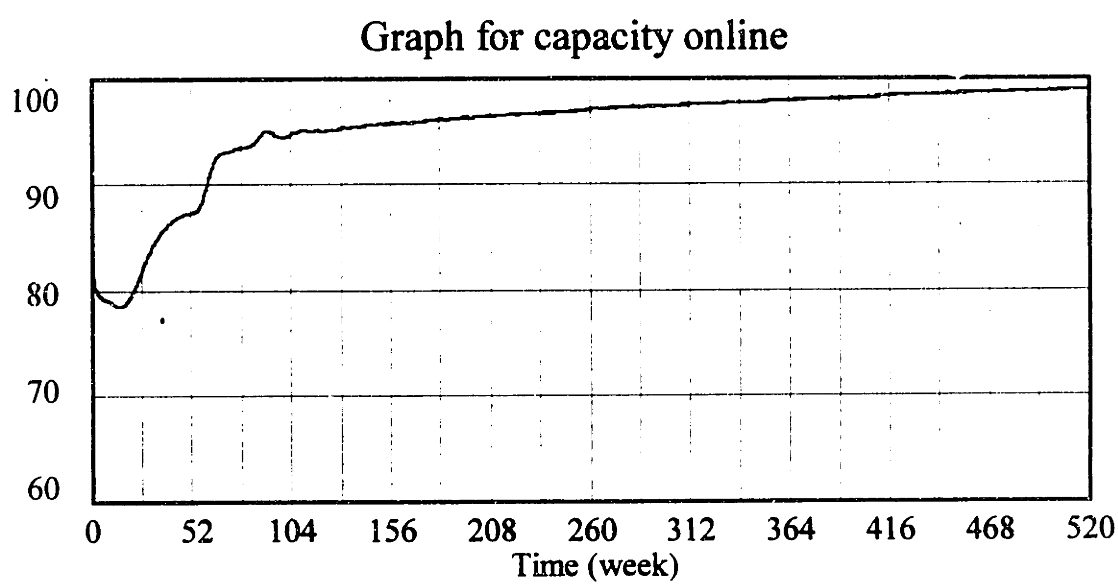


Variable 173



capacity online - BASE ———— percentage
capacity online - FRD01 ········ percentage
capacity online - FRD02 - - - - percentage

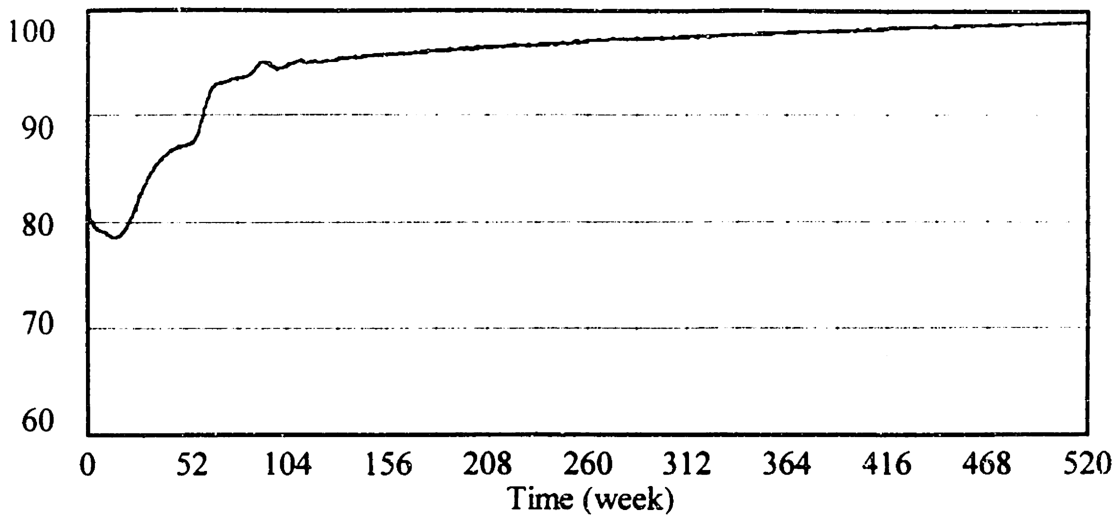
Variable 174



capacity online - BASE ———— percentage
capacity online - TAR05 ········ percentage
capacity online - TAR15 - - - - percentage
capacity online - TAR20 -·-·-·- percentage

Variable 175

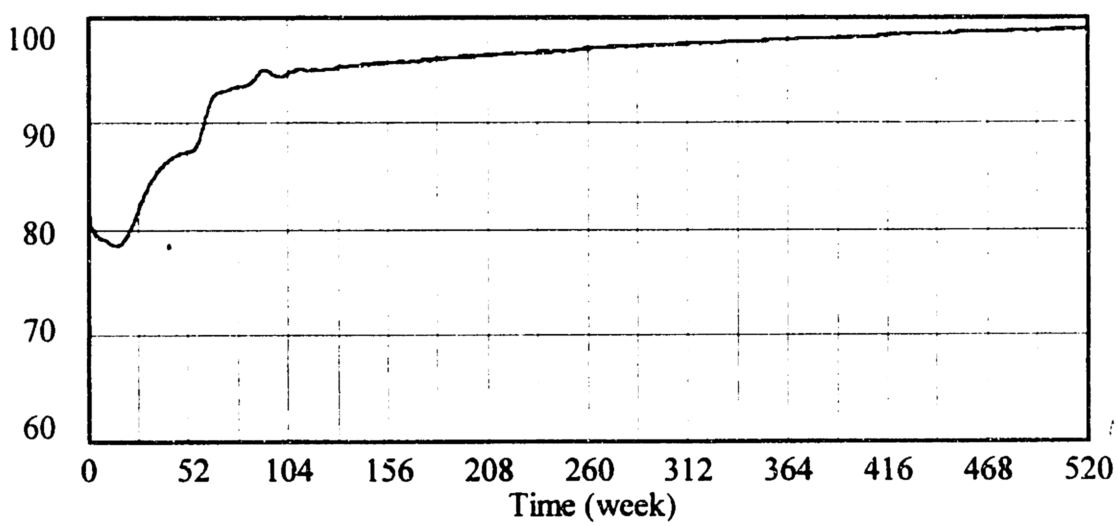
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - TCR6 ········ percentage
capacity online - TCR9 - - - - percentage
capacity online - TCR18 -·-·-·- percentage

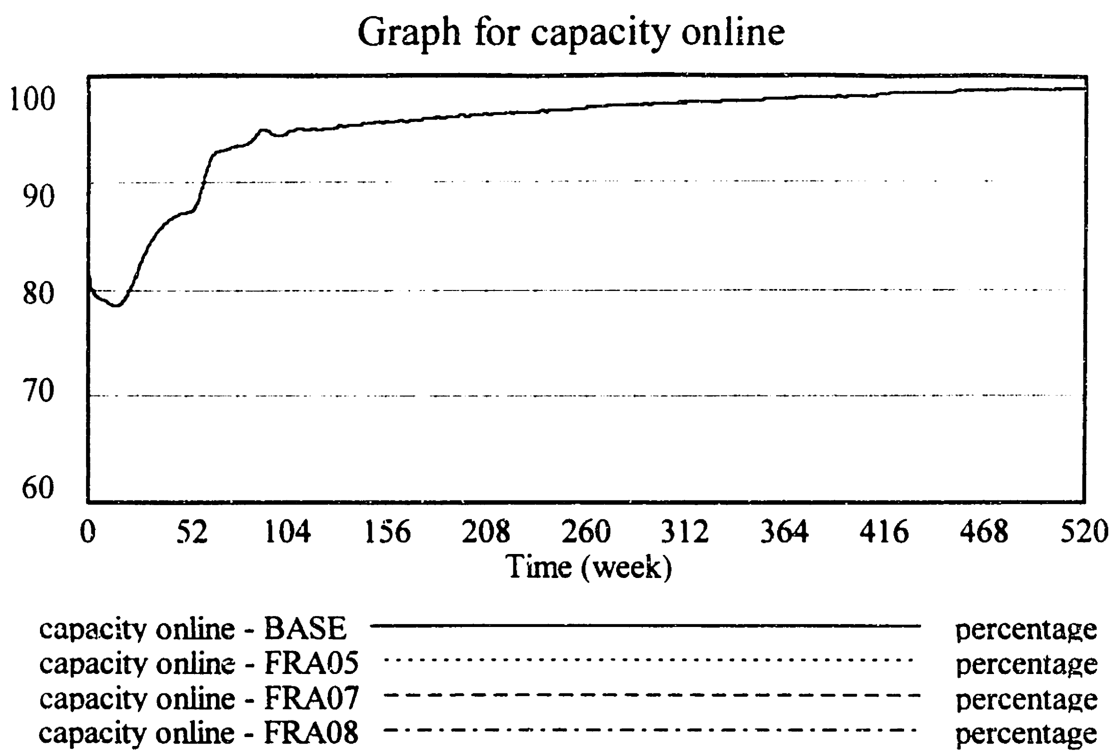
Variable 176

Graph for capacity online

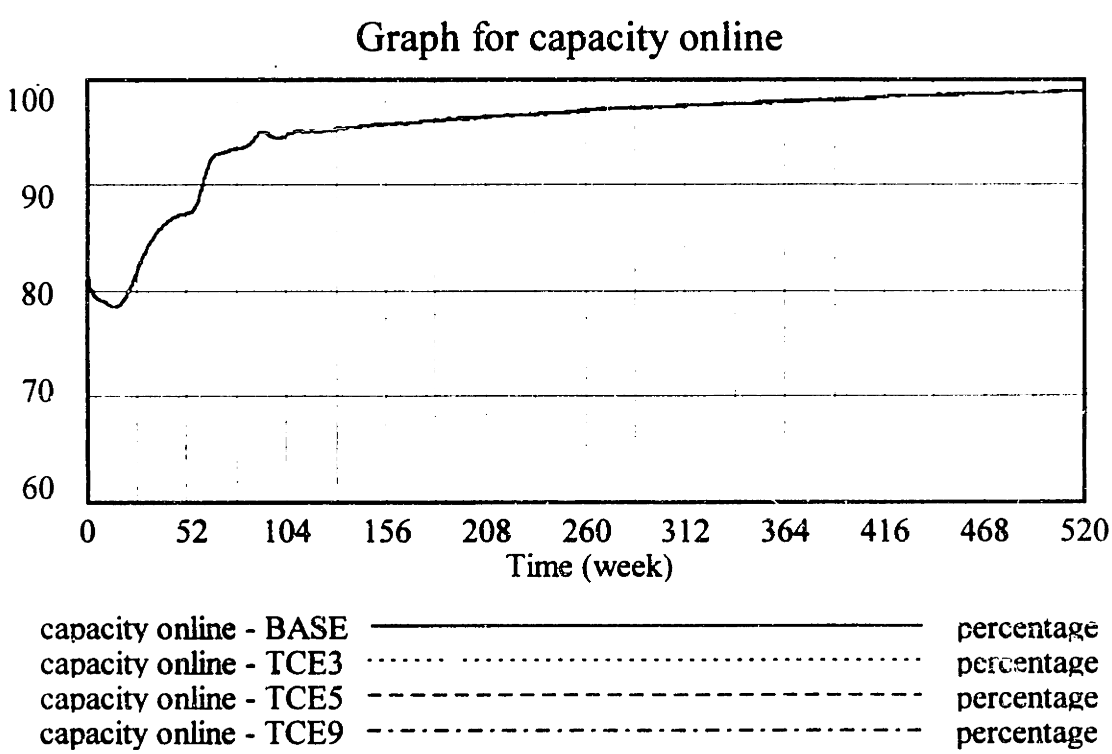


capacity online - BASE ———— percentage
capacity online - CPR200 ········ percentage
capacity online - CPR225 - - - - percentage
capacity online - CPR275 -·-·-·- percentage

Variable 177

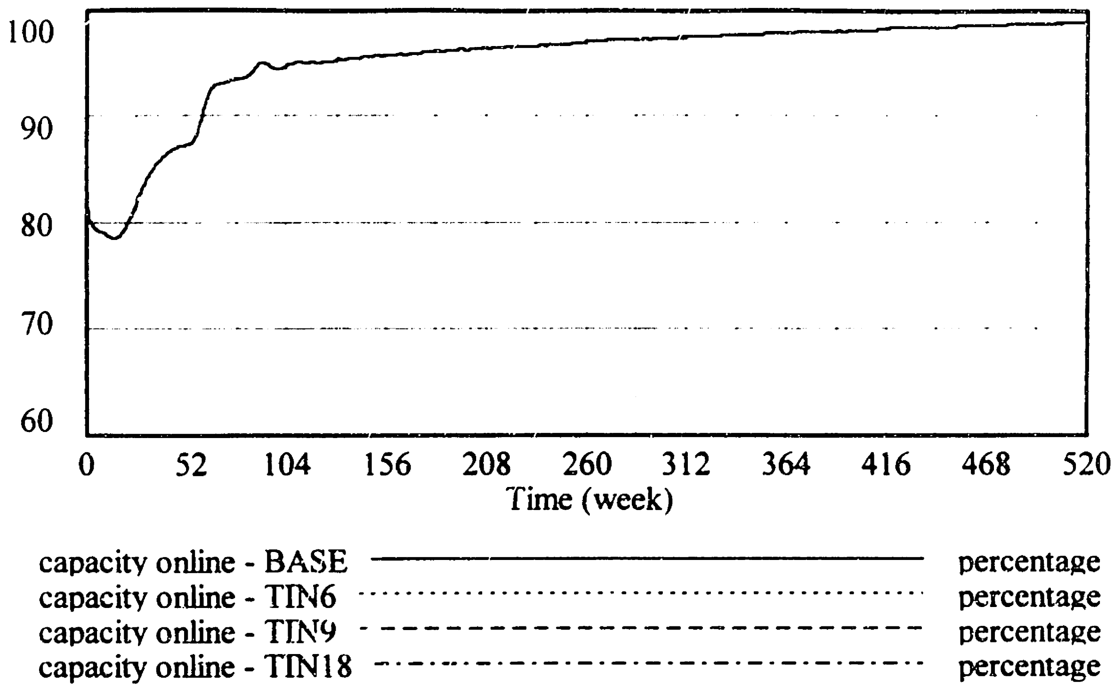


Variable 178



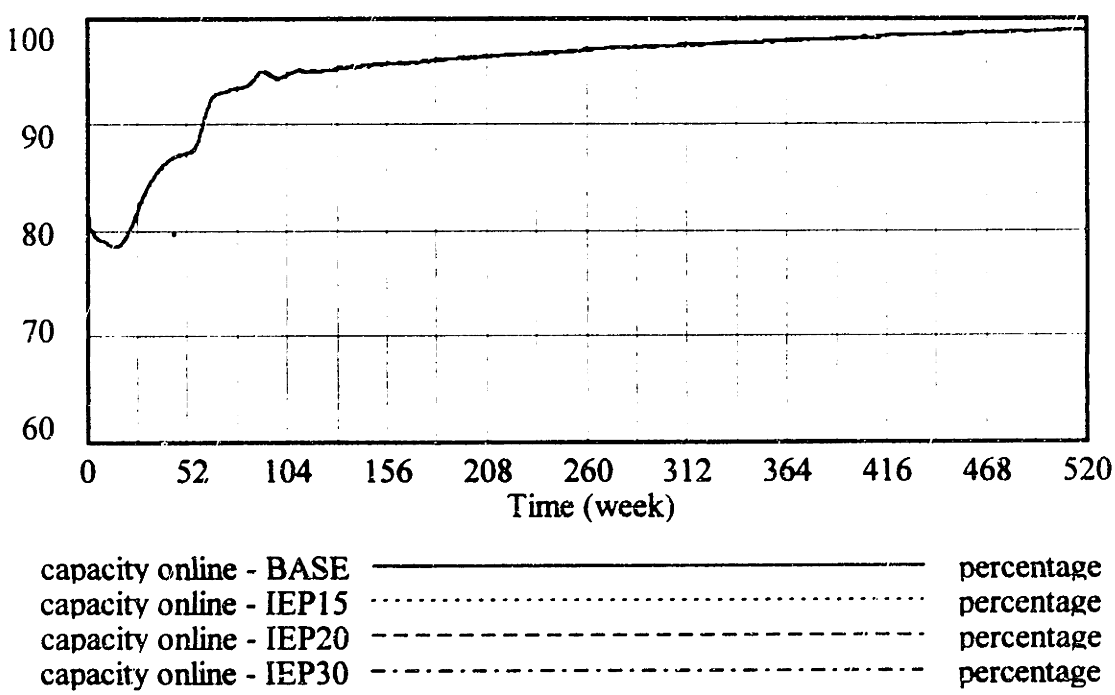
Variable 179

Graph for capacity online

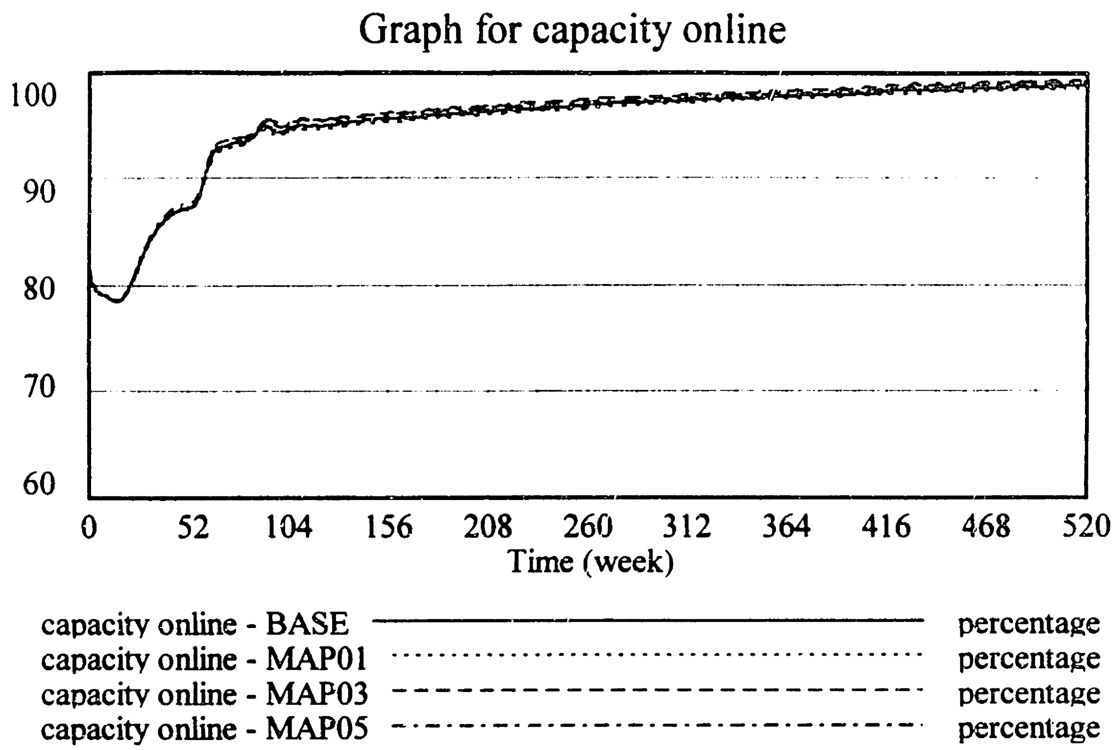


Variable 180

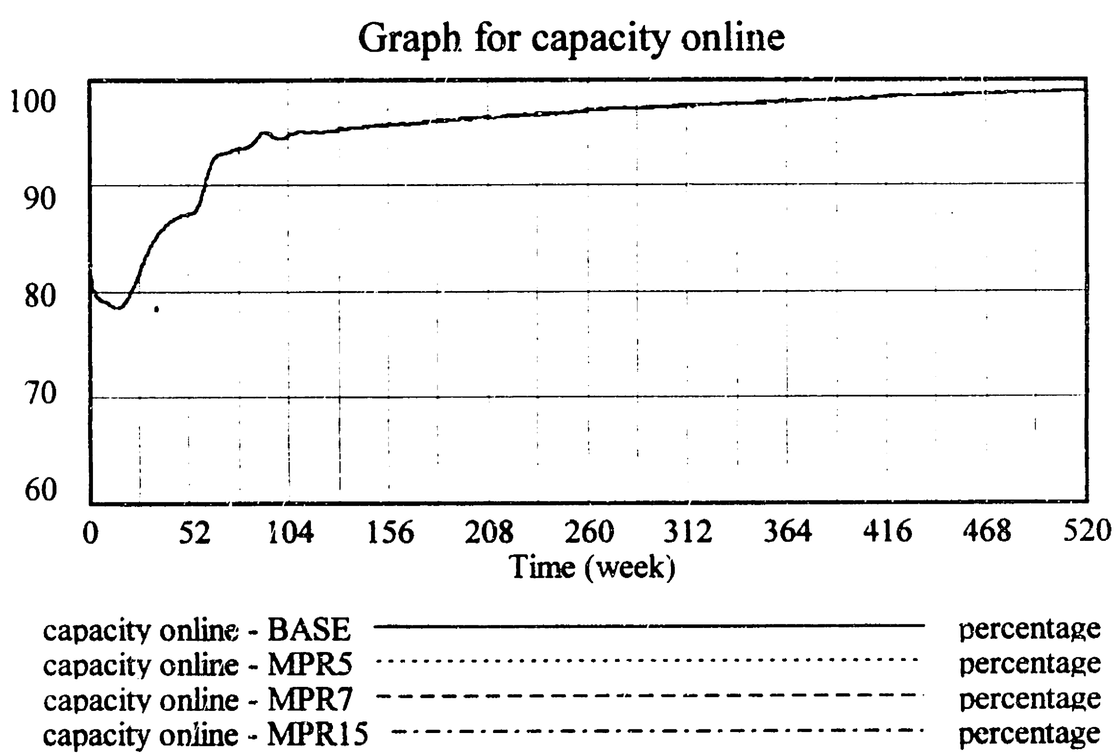
Graph for capacity online



Variable 181

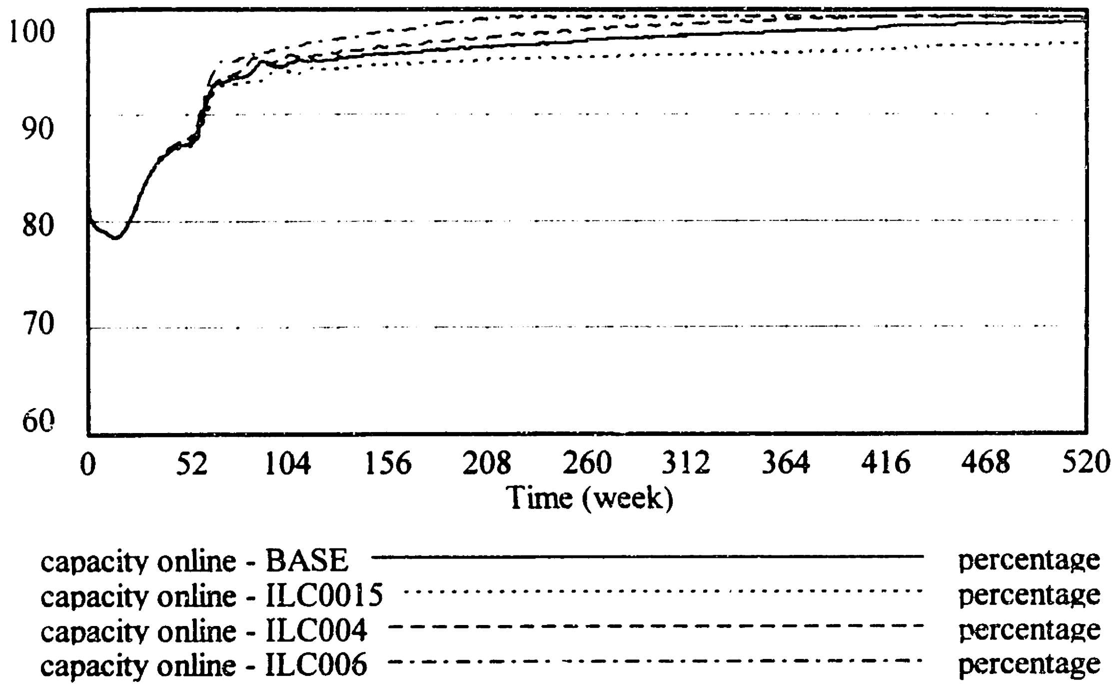


Variable 182



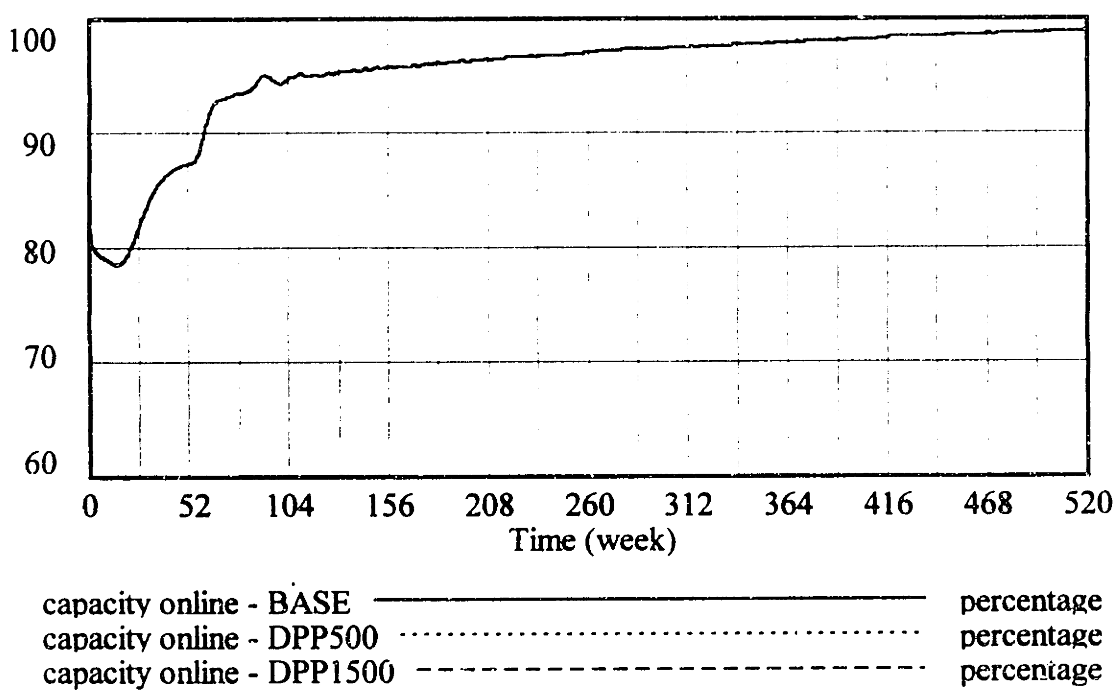
Variable 183

Graph for capacity online



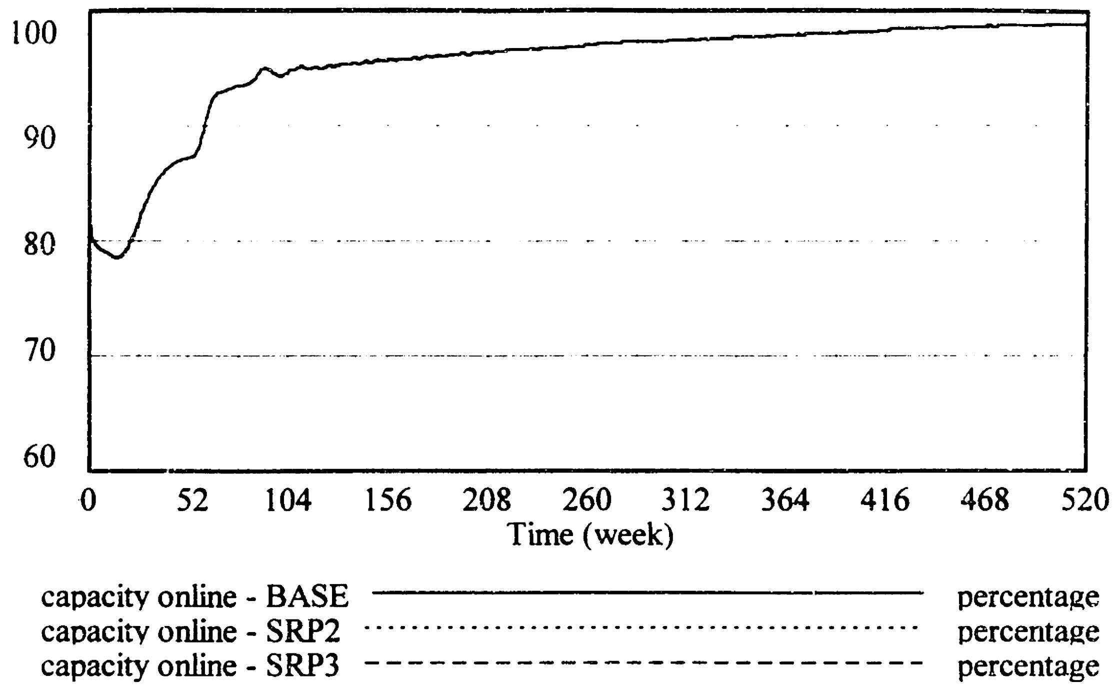
Variable 184

Graph for capacity online



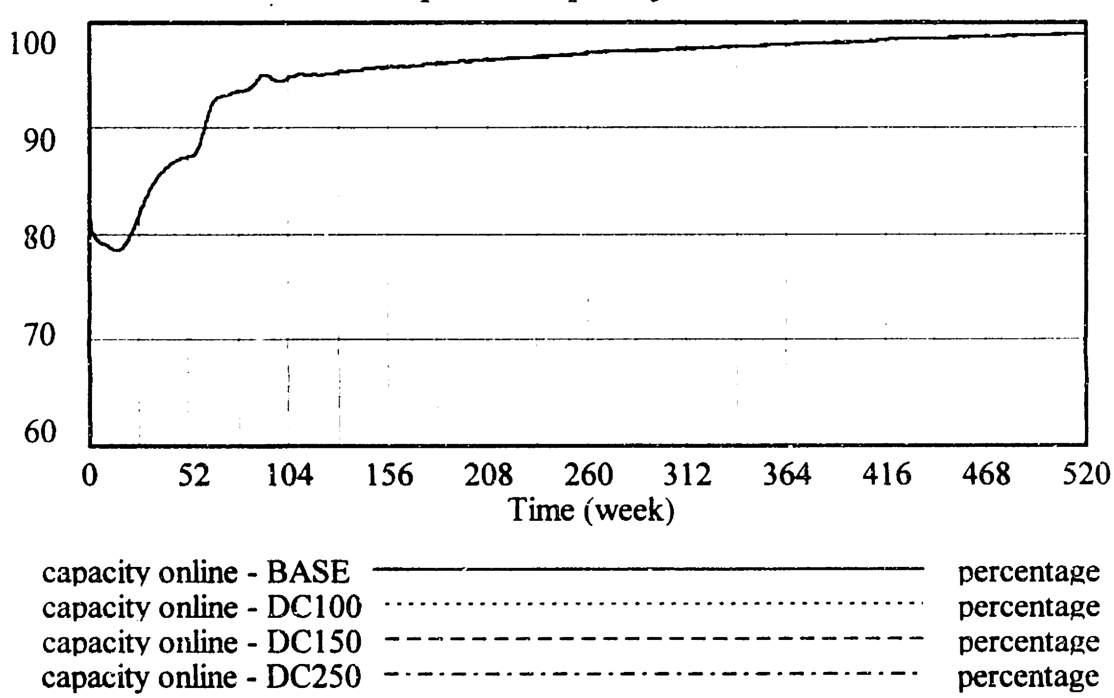
Variable 185

Graph for capacity online



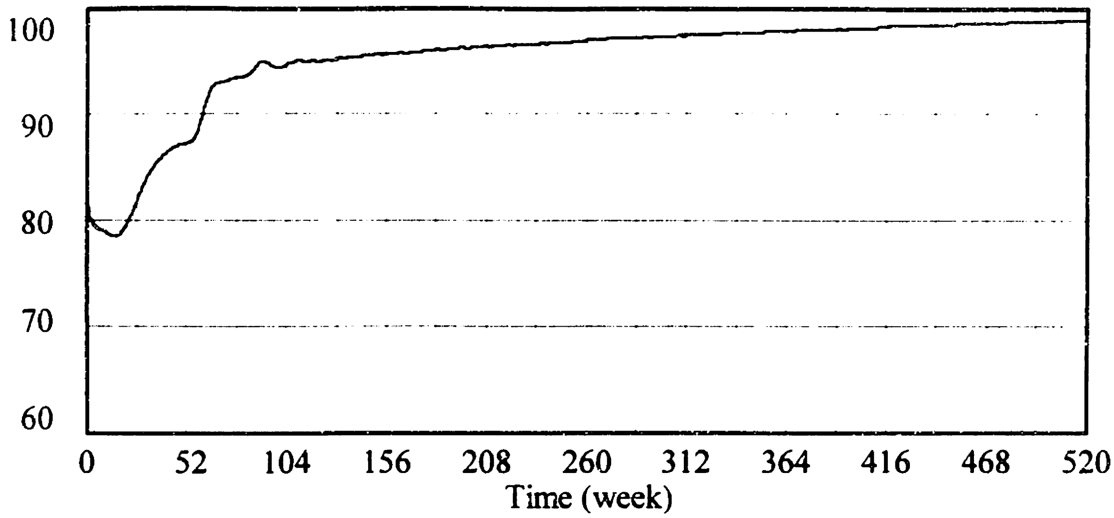
Variable 186

Graph for capacity online



Variable 187

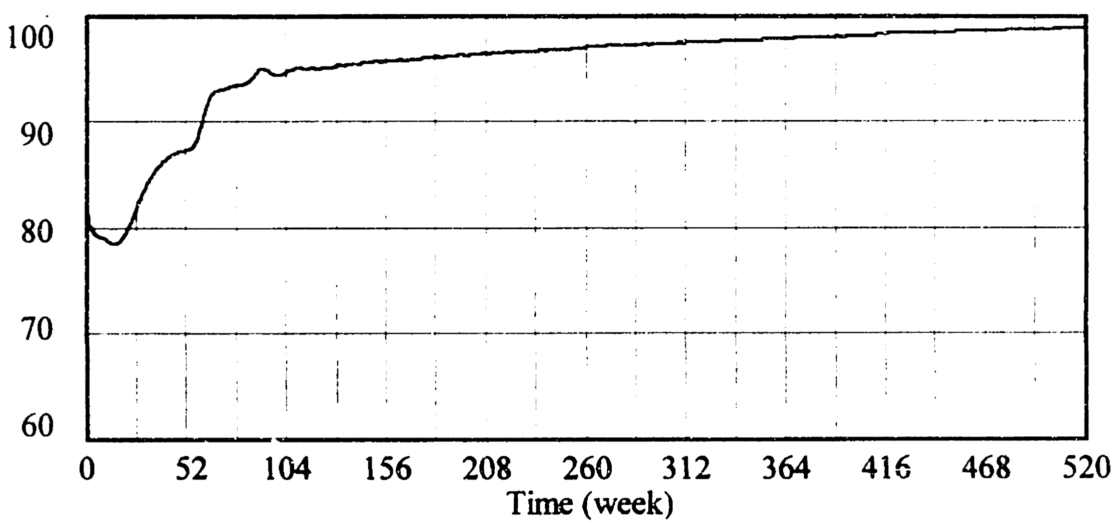
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - DF05 ········ percentage
capacity online - DF06 - - - - percentage
capacity online - DF07 -·-·-·- percentage

Variable 188

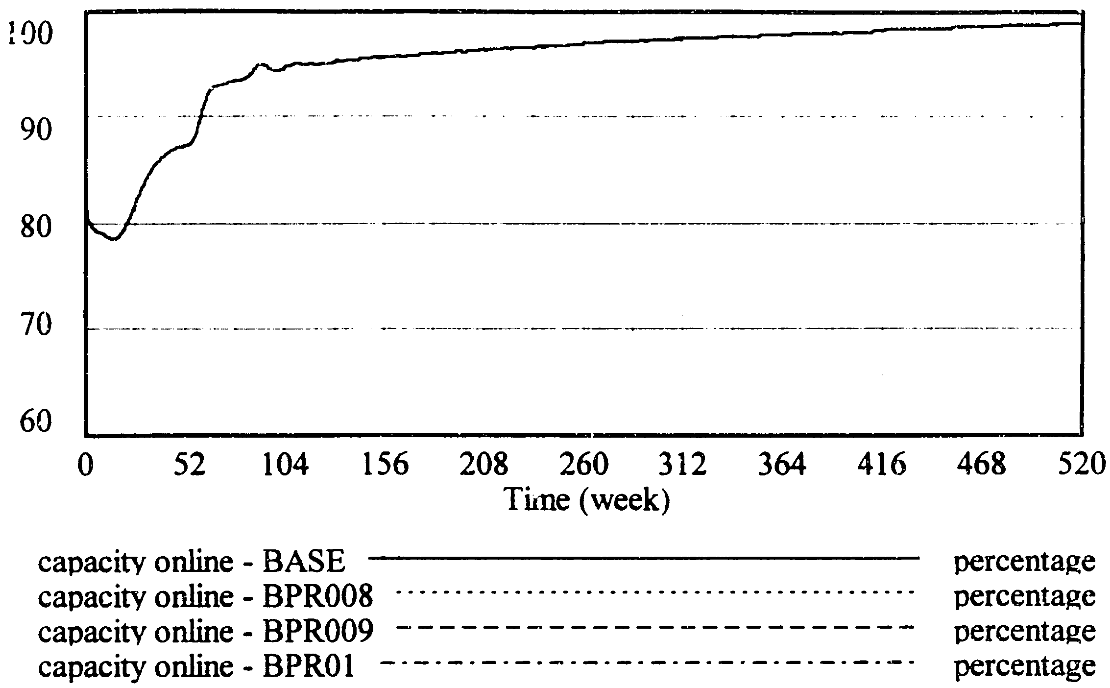
Graph for capacity online



capacity online - BASE ———— percentage
capacity online - DR3 ········ percentage
capacity online - DR5 - - - - percentage
capacity online - DR7 -·-·-·- percentage

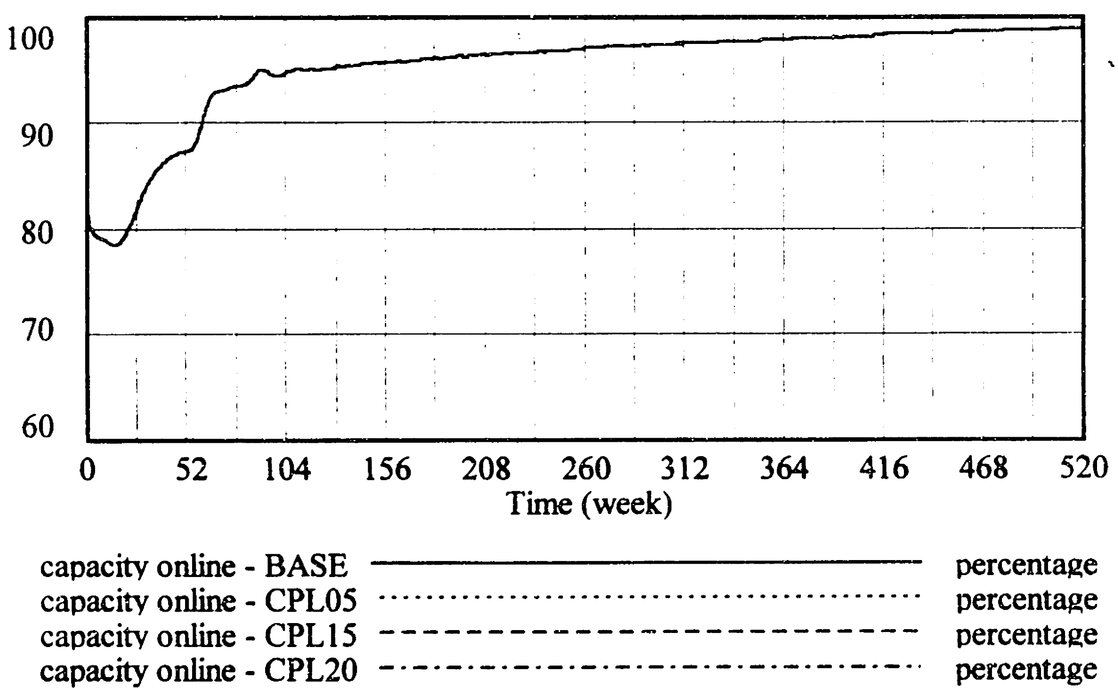
Variable 189

Graph for capacity online

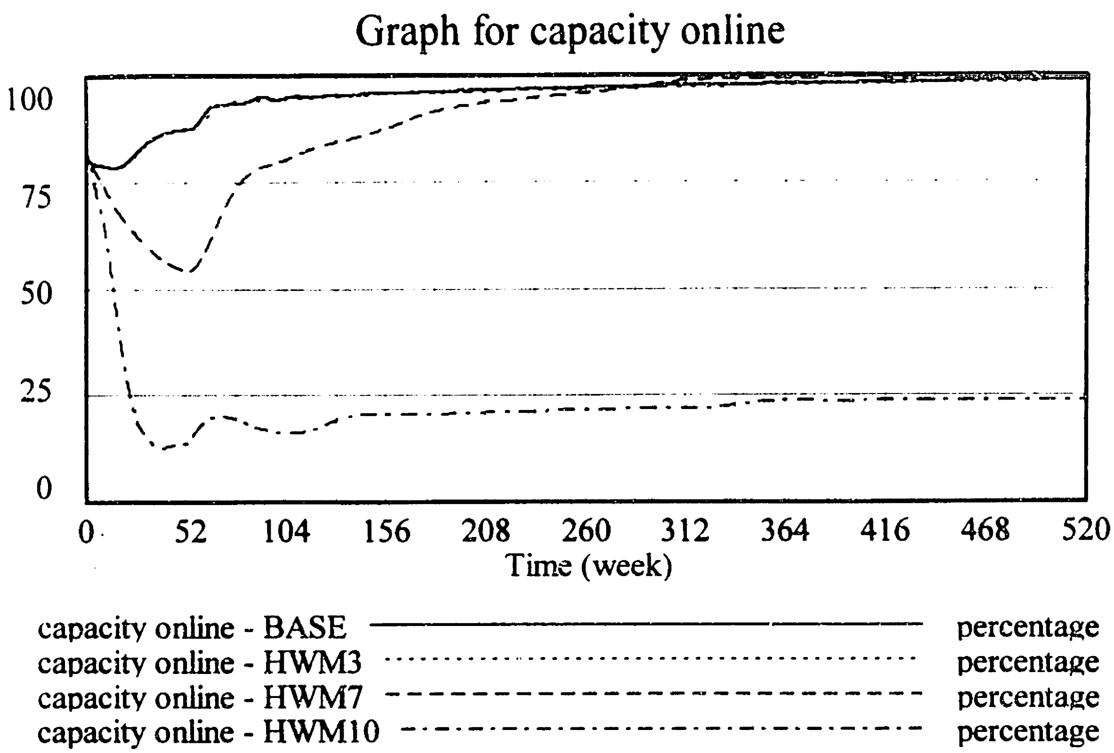


Variable 190

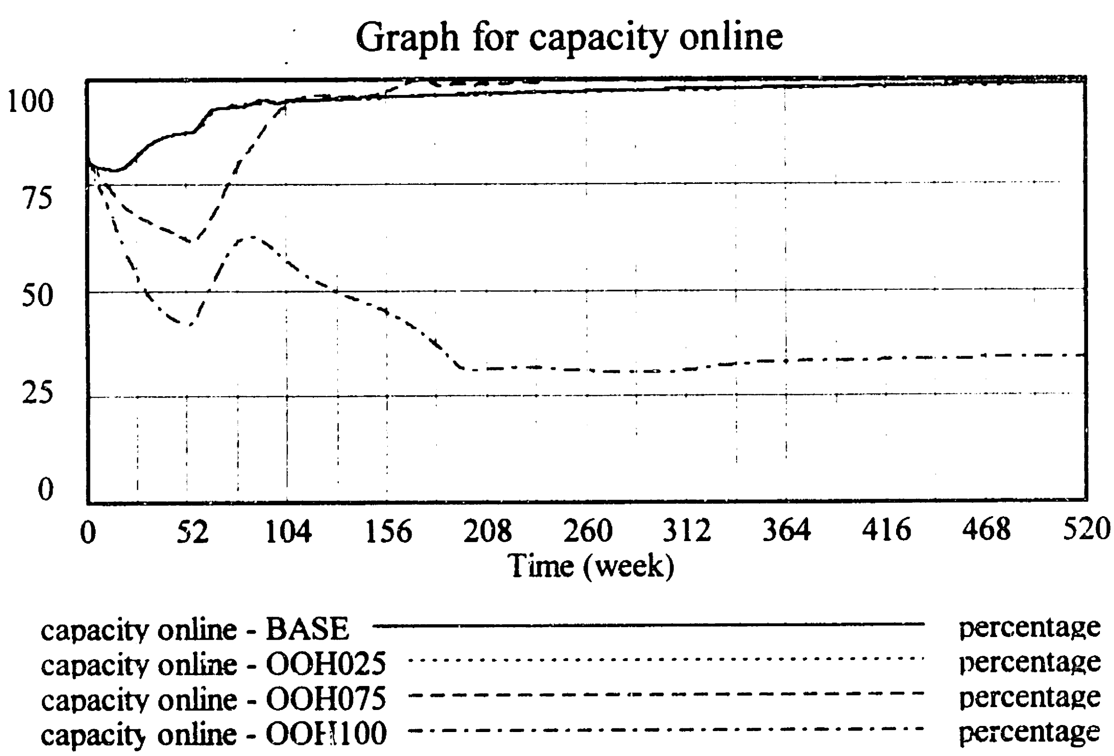
Graph for capacity online



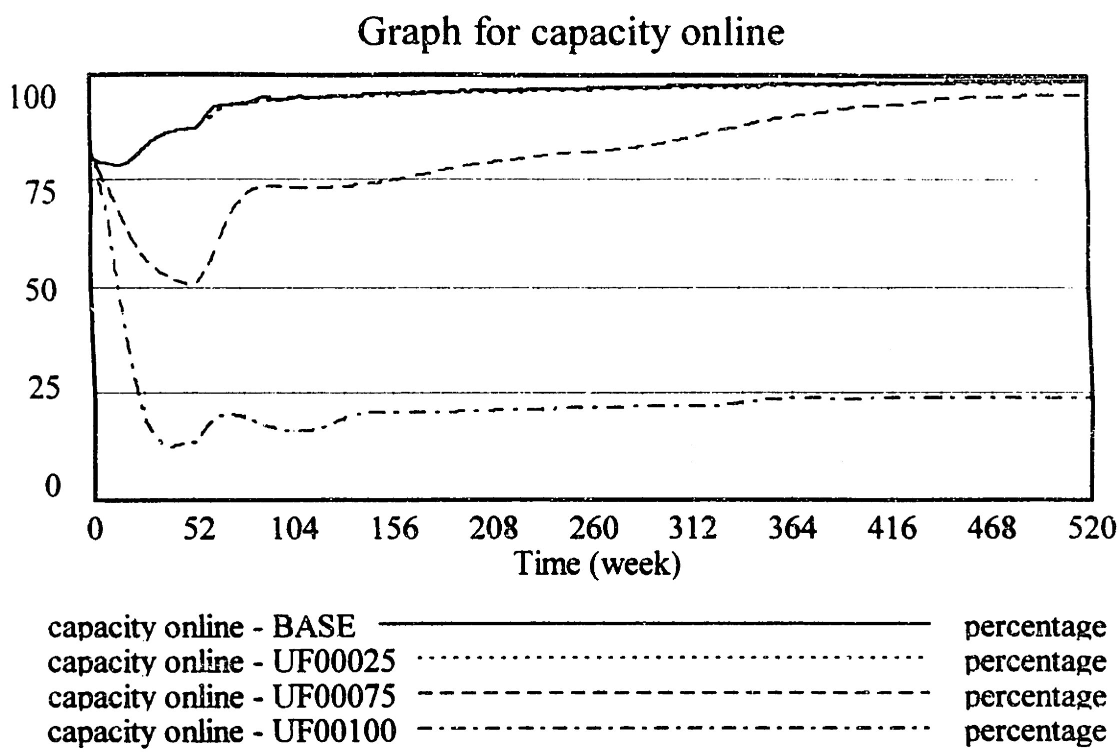
Variable 191



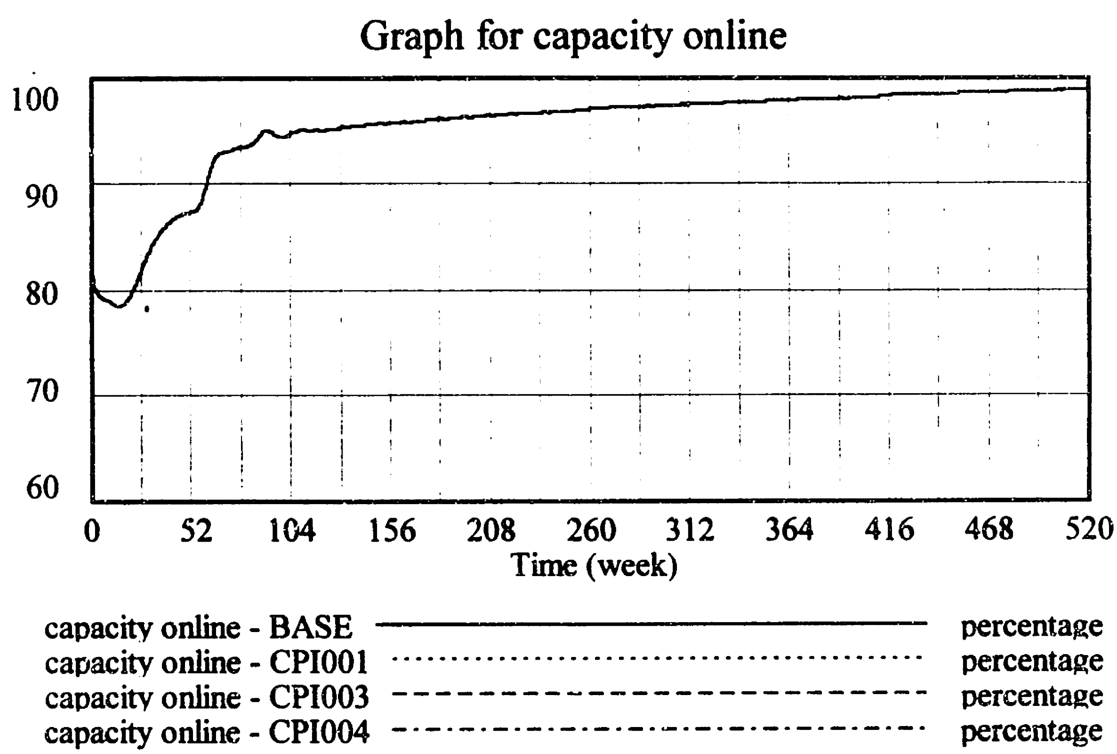
Variable 192



Variable 193

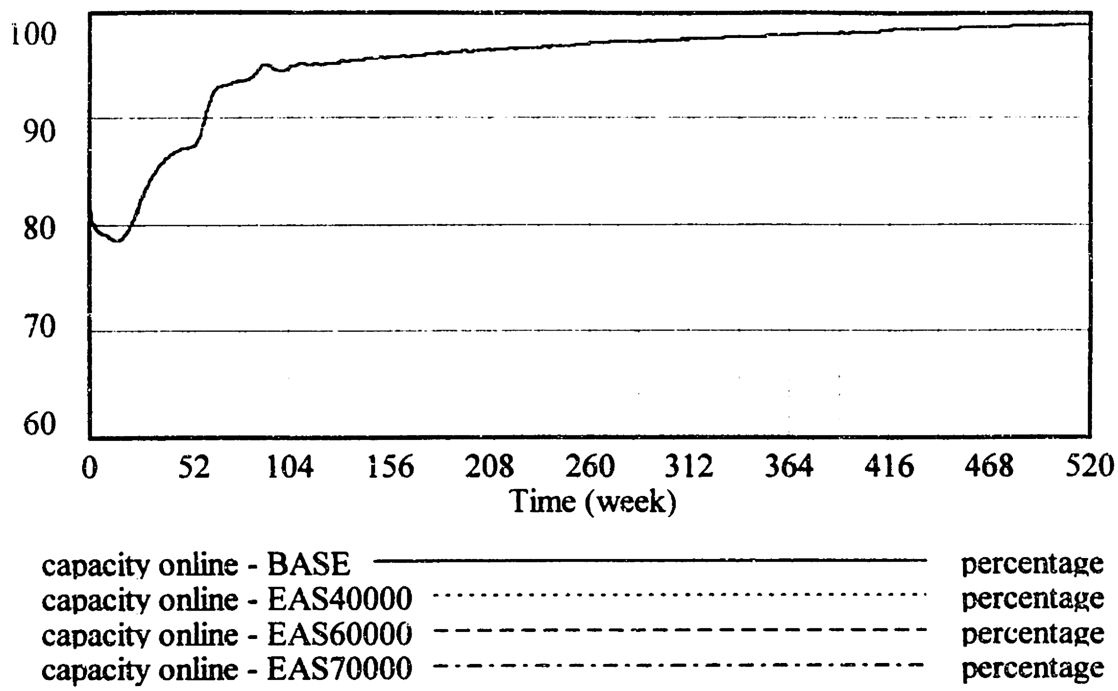


Variable 194



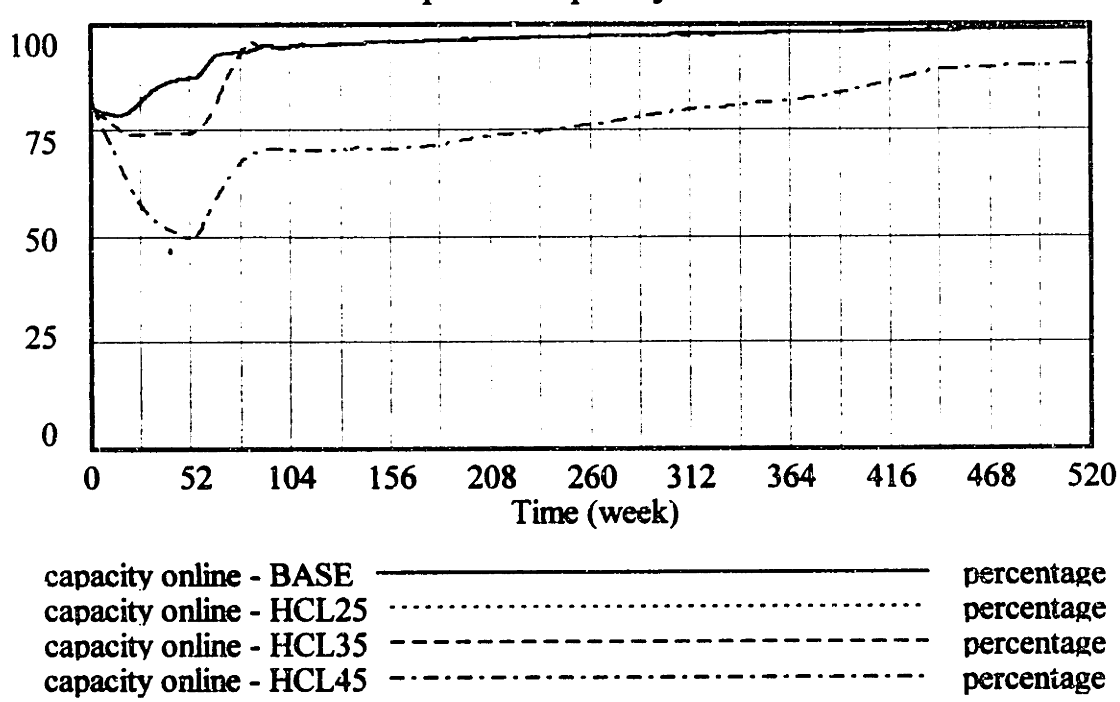
Variable 195

Graph for capacity online

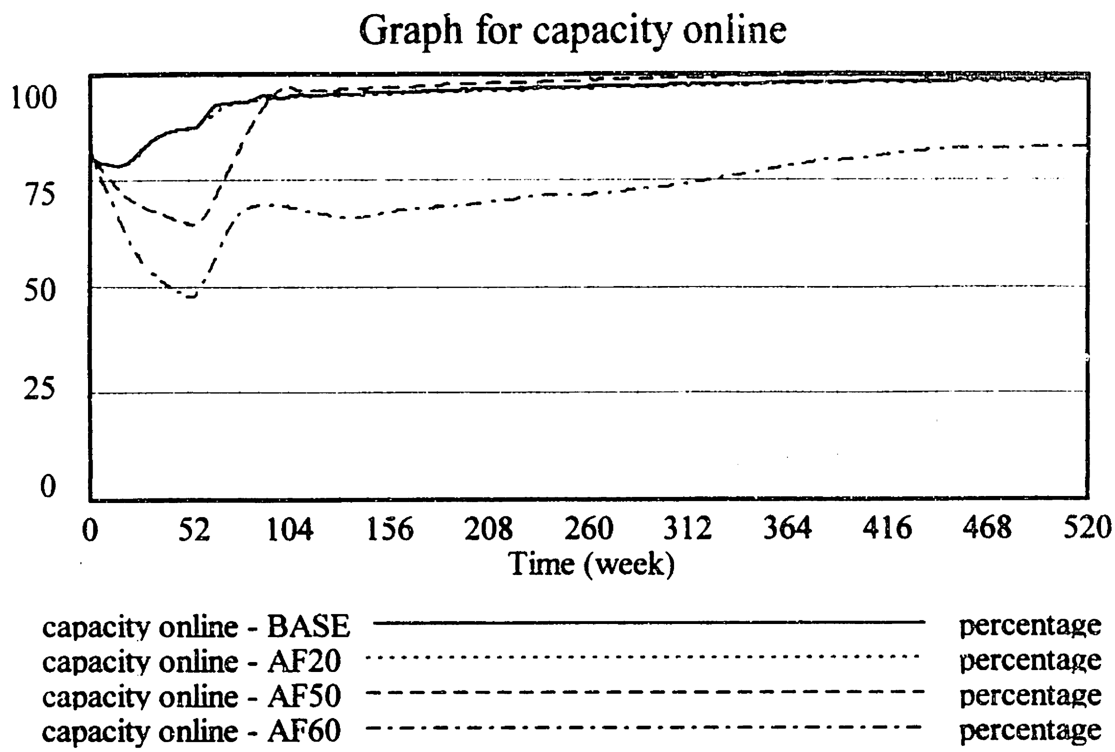


Variable 196

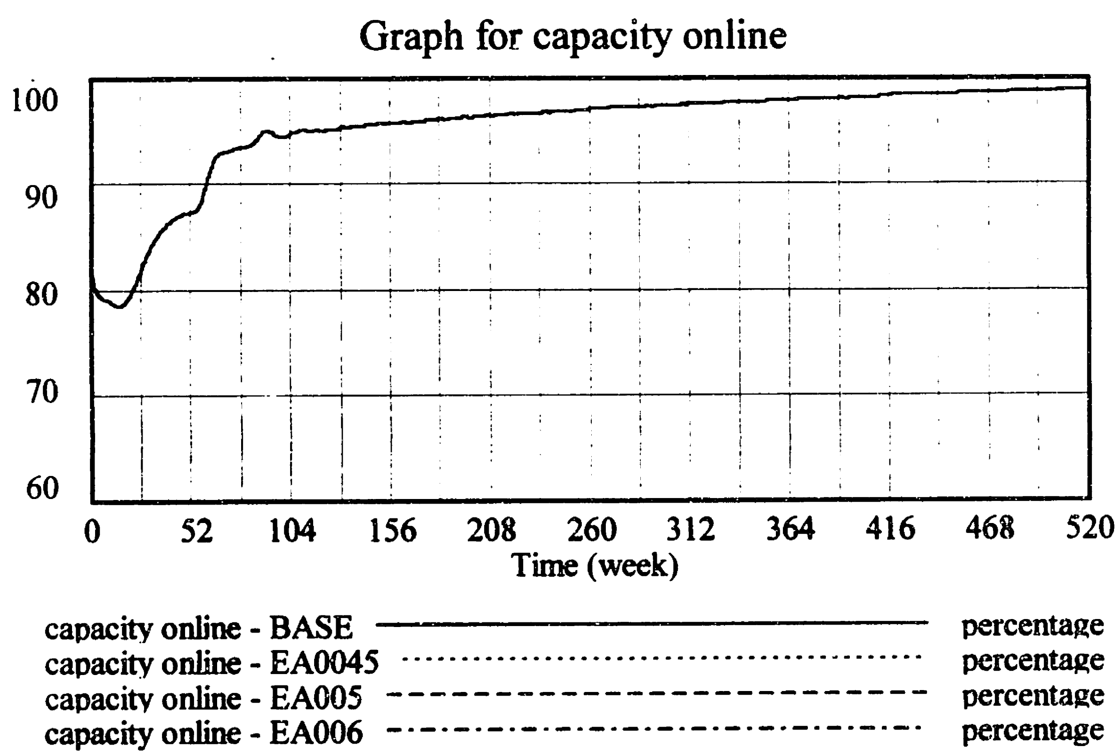
Graph for capacity online



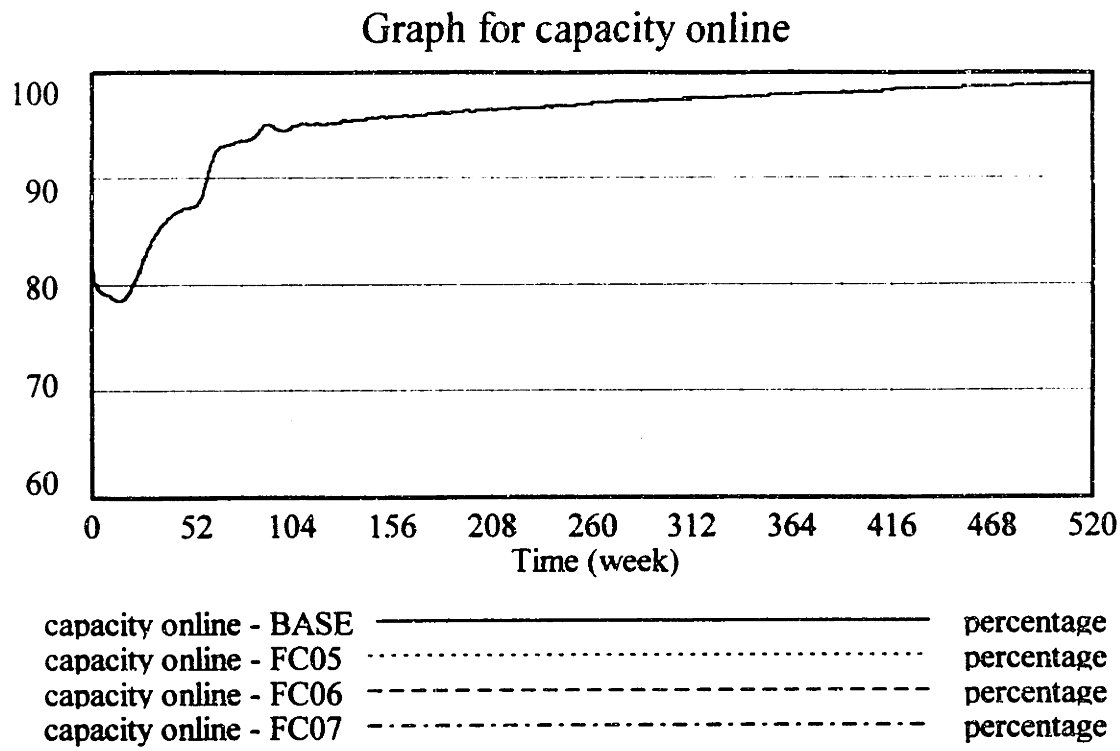
Variable 197



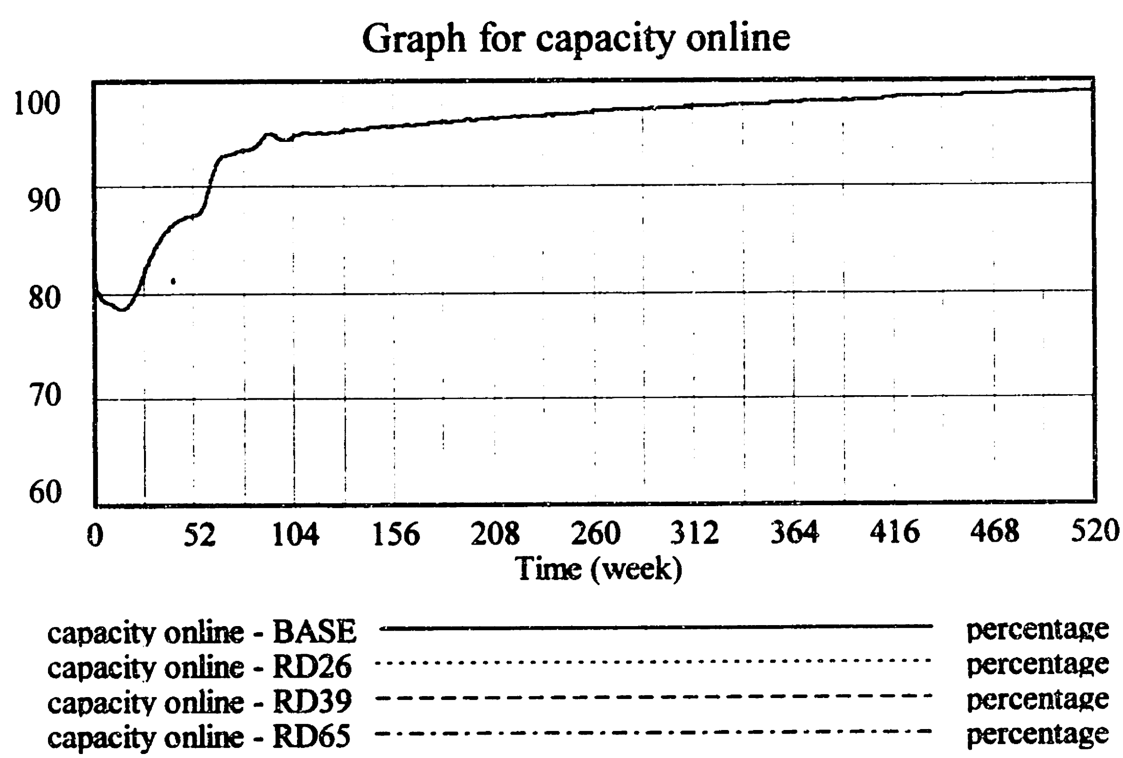
Variable 199



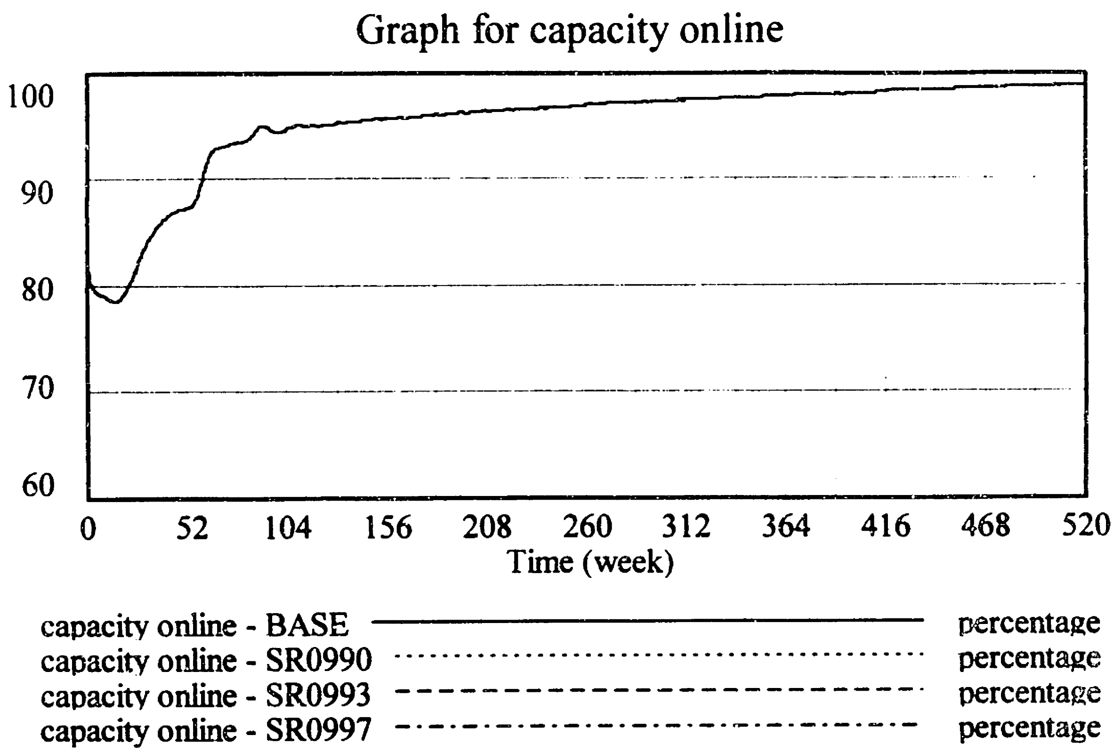
Variable 200



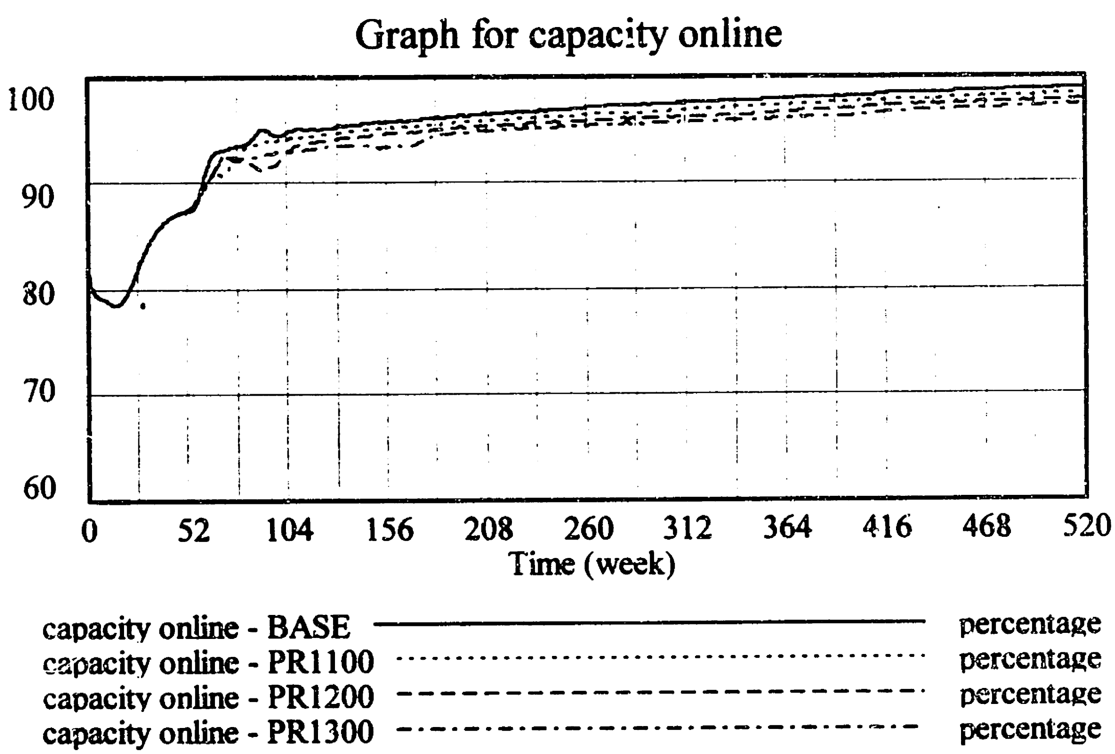
Variable 201



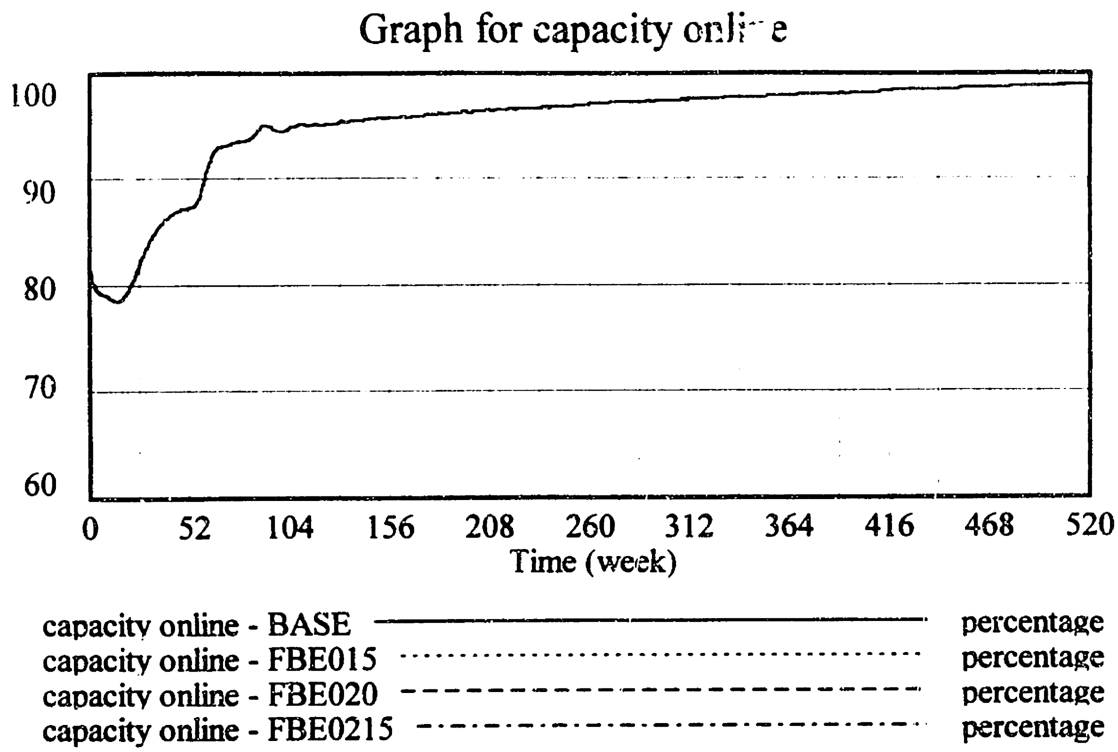
Variable 202



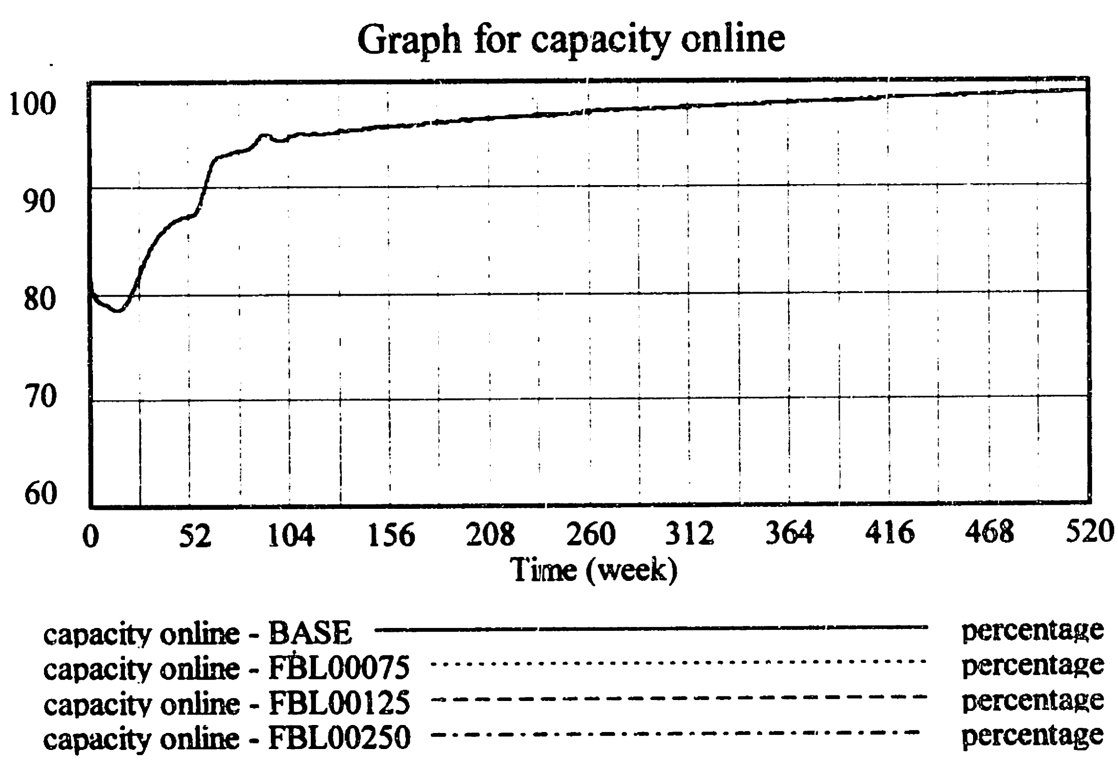
Variable 203



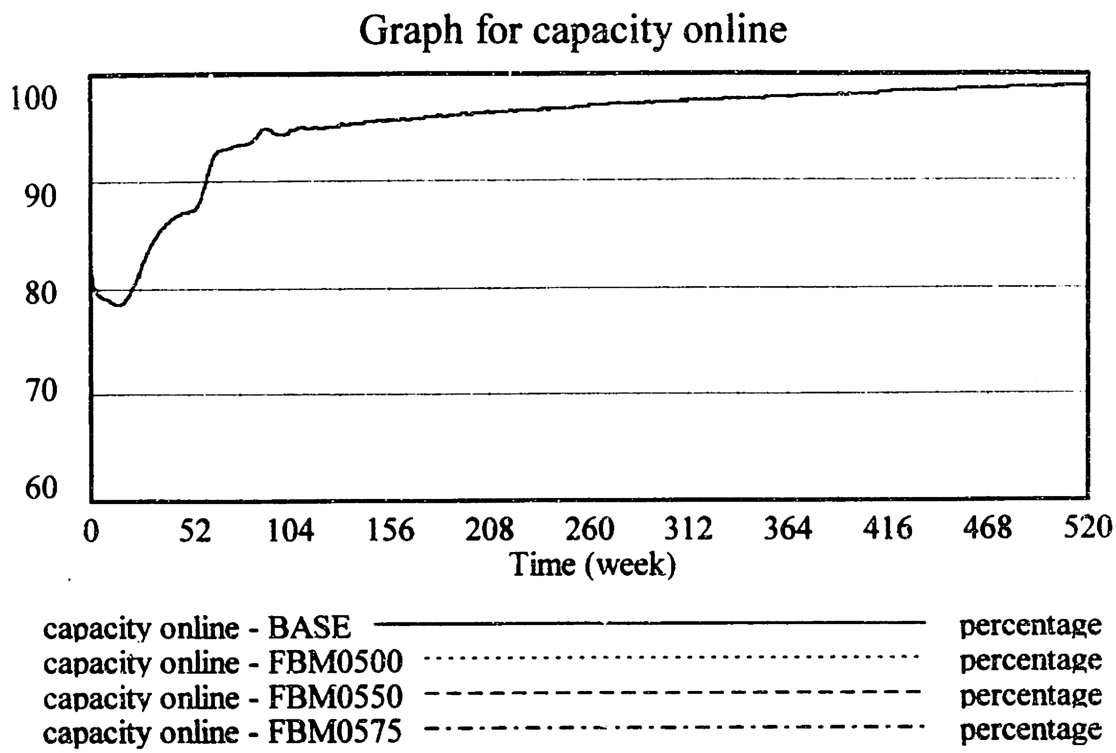
Variable 204



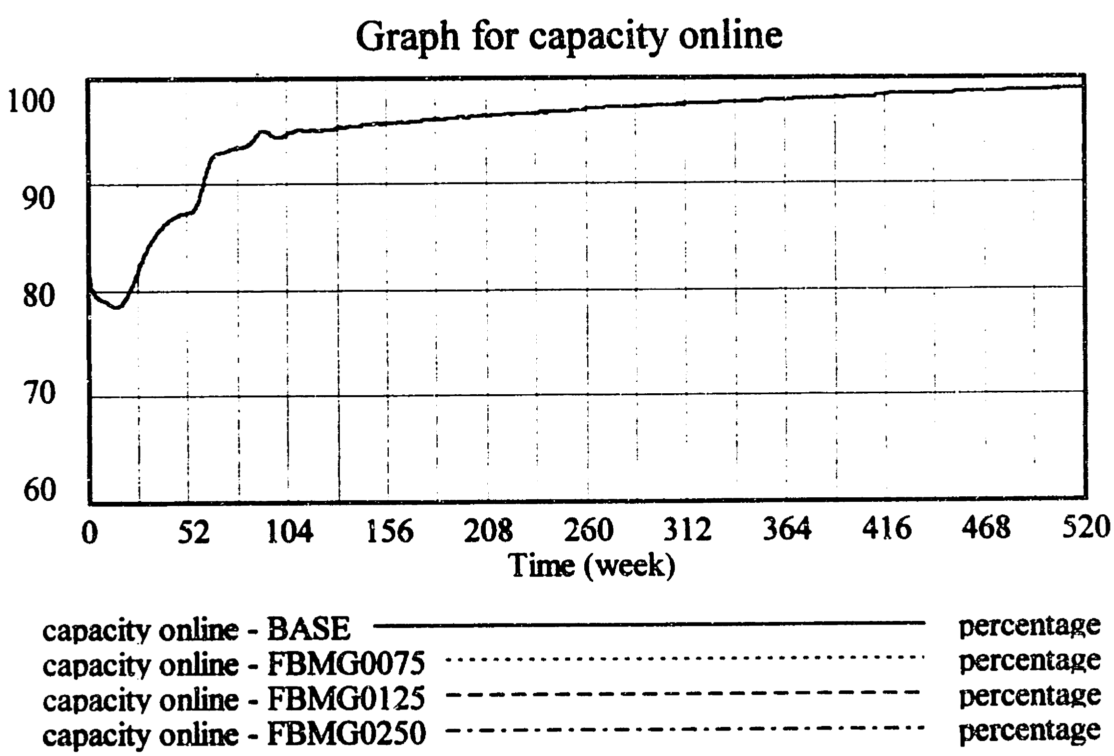
Variable 205



Variable 206

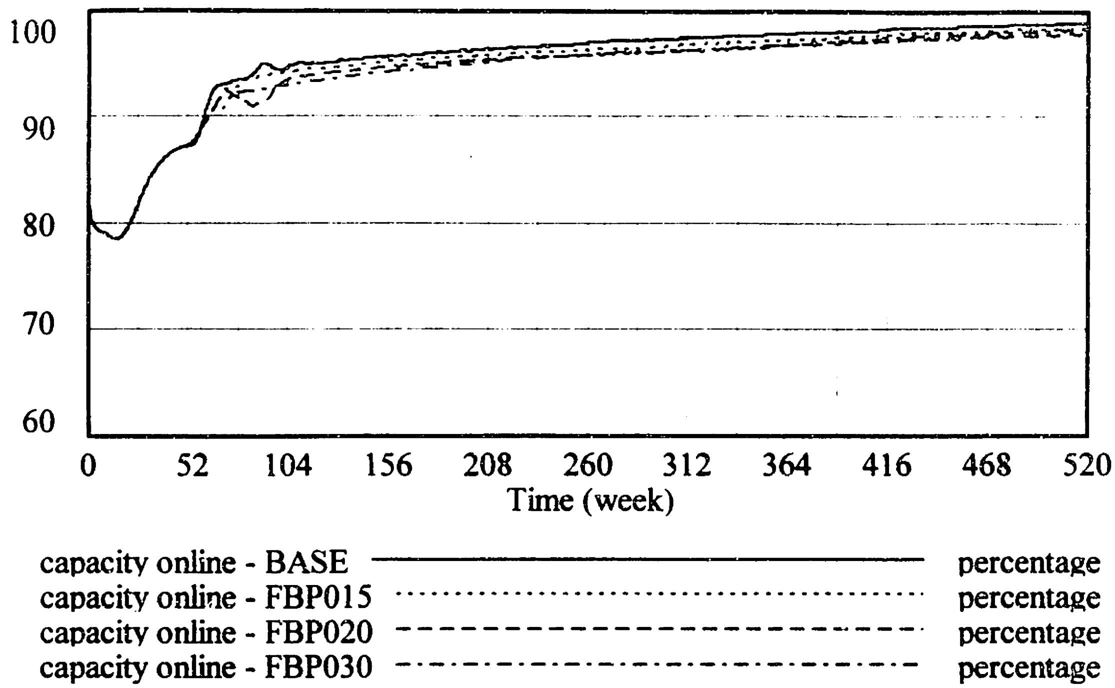


Variable 207



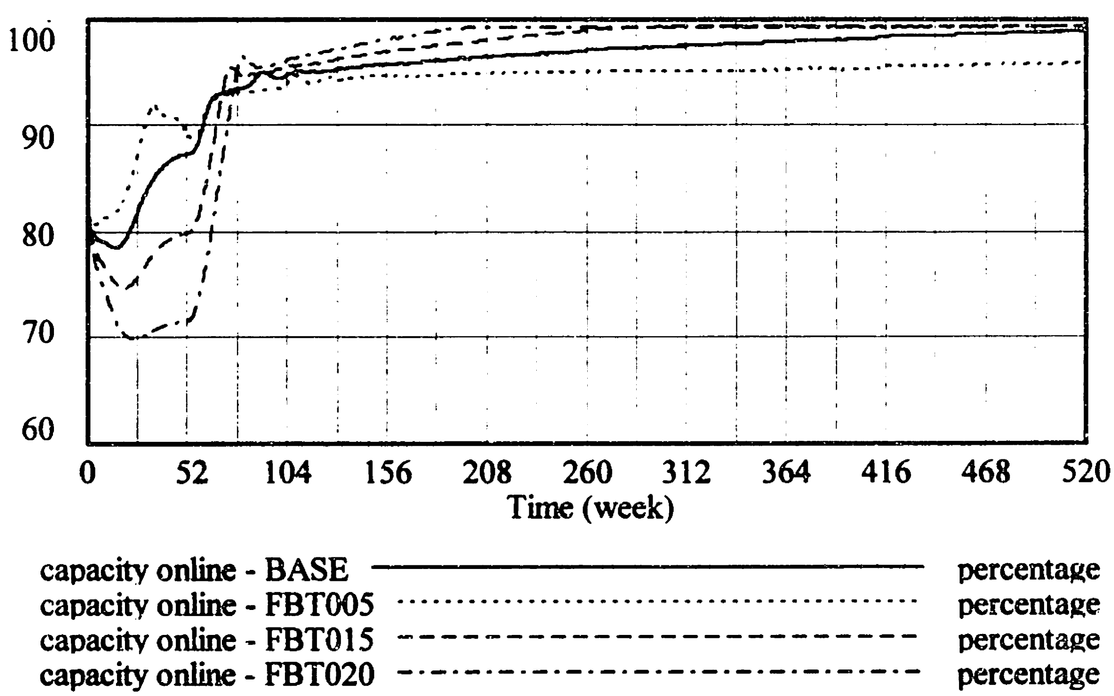
Variable 208

Graph for capacity online



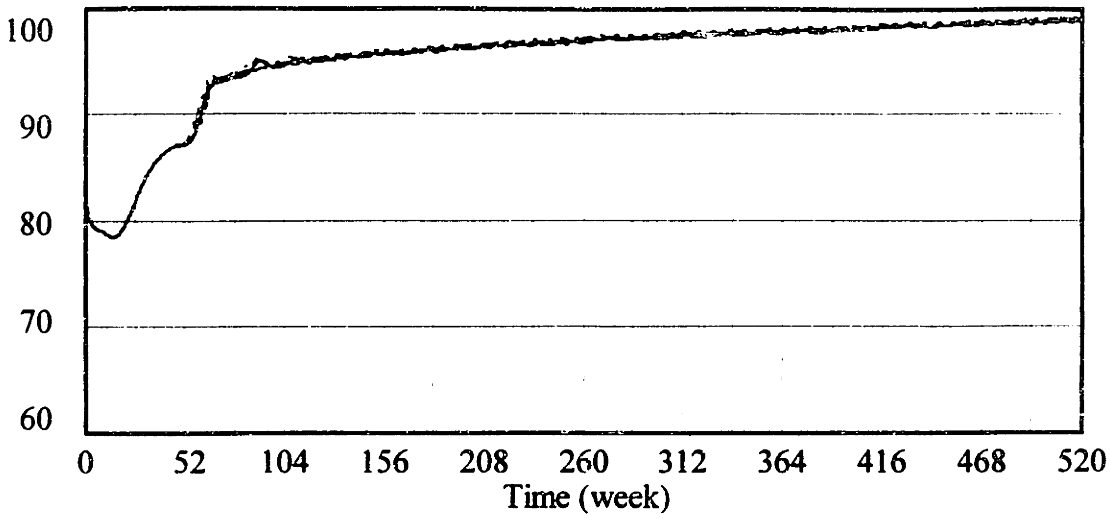
Variable 209

Graph for capacity online



Variable 210

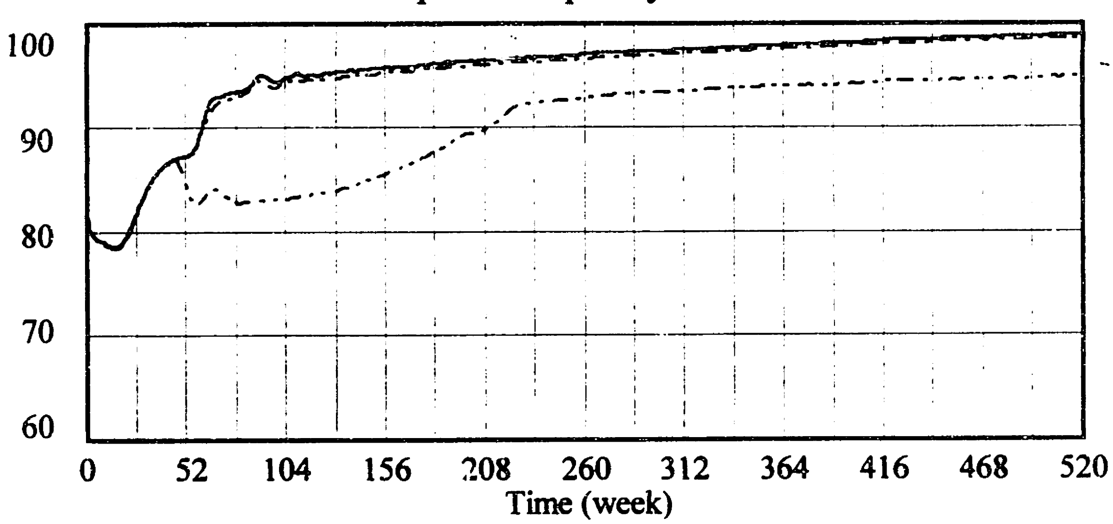
Graph for capacity online



capacity online - BASE ——— percentage
capacity online - FPB06 ········ percentage
capacity online - FPB07 - - - - percentage
capacity online - FPB09 -·-·-·- percentage

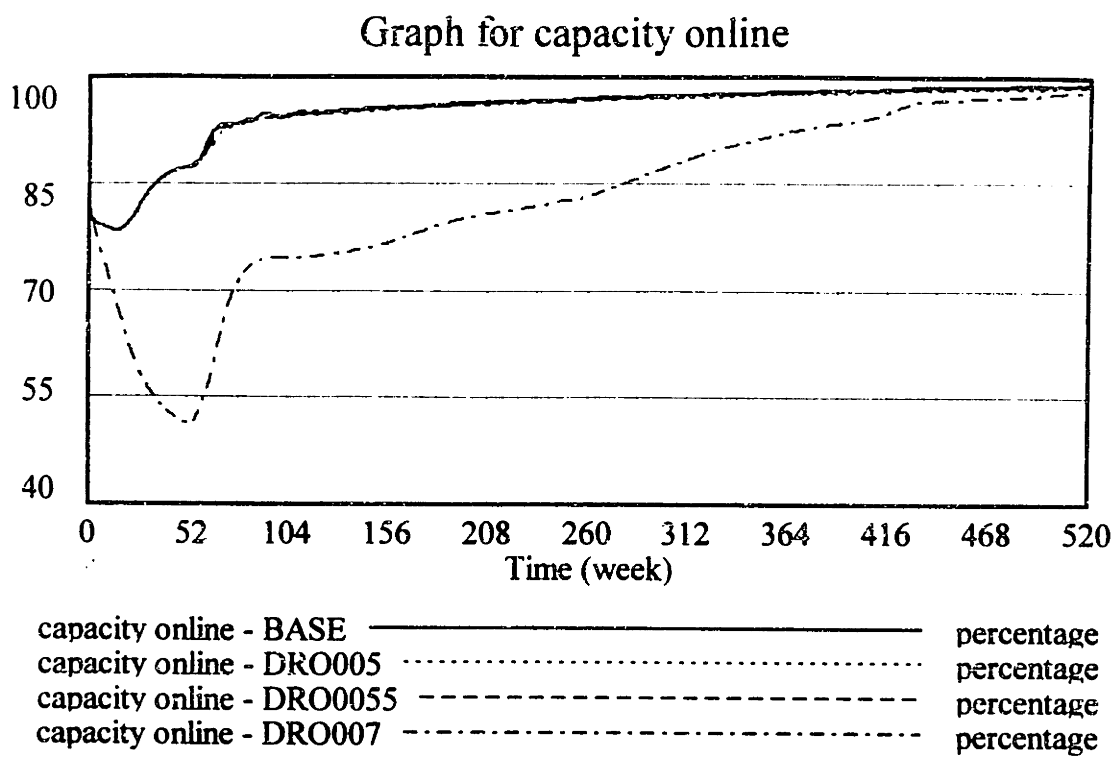
Variable 211

Graph for capacity online

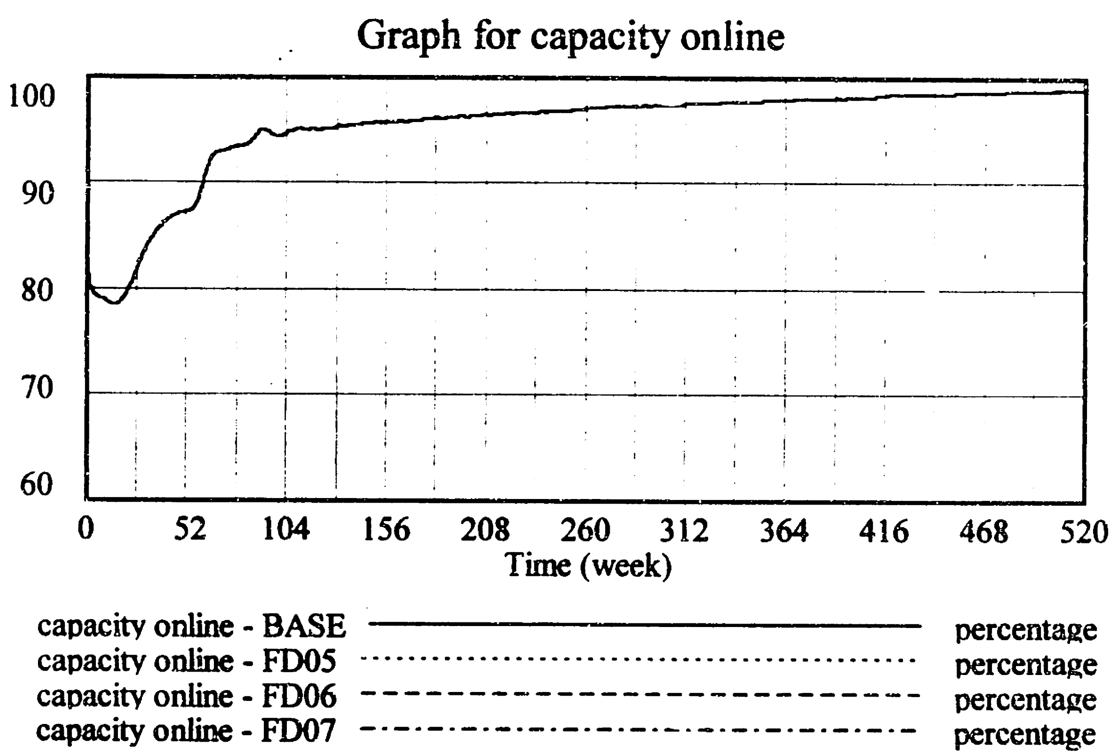


capacity online - BASE ——— percentage
capacity online - MAS75000 ········ percentage
capacity online - MAS125000 - - - - percentage
capacity online - MAS150000 -·-·-·- percentage
capacity online - MAS175000 -··-··- percentage

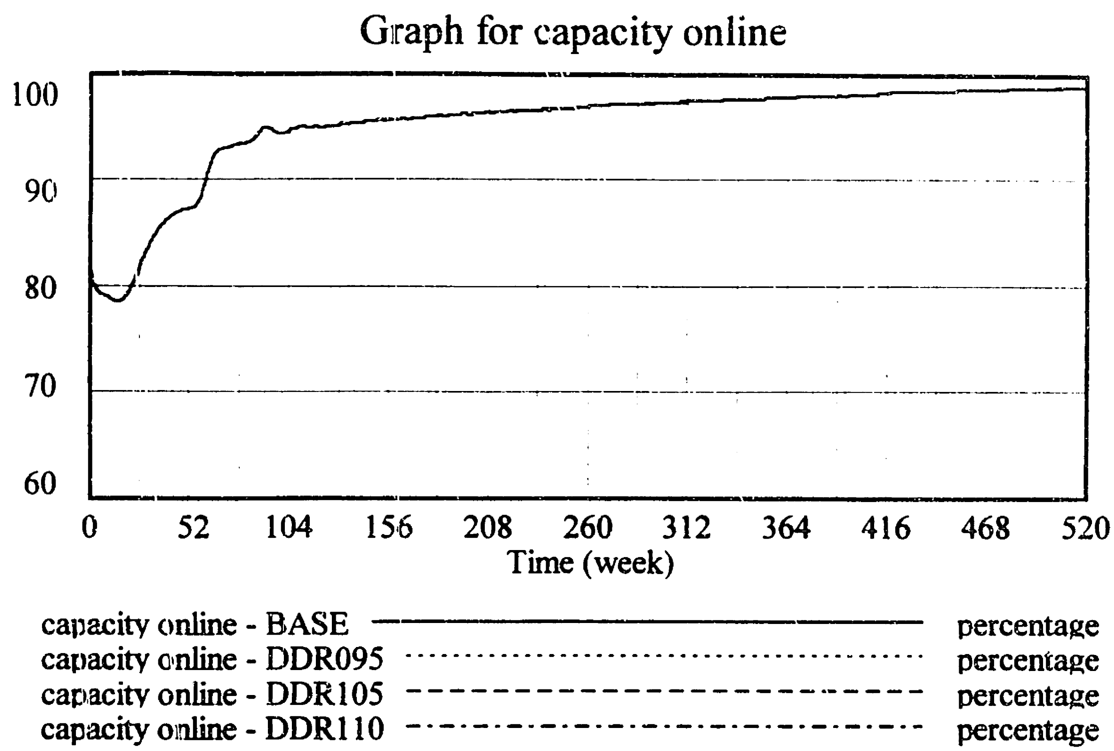
Variable 212



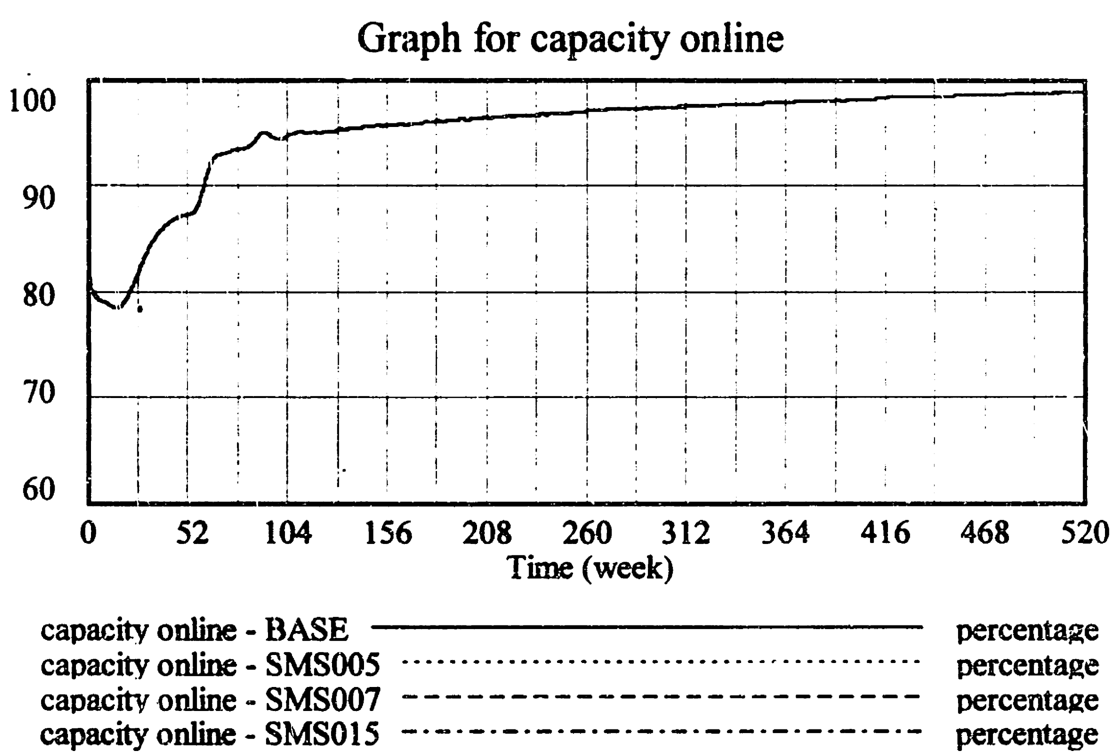
Variable 213



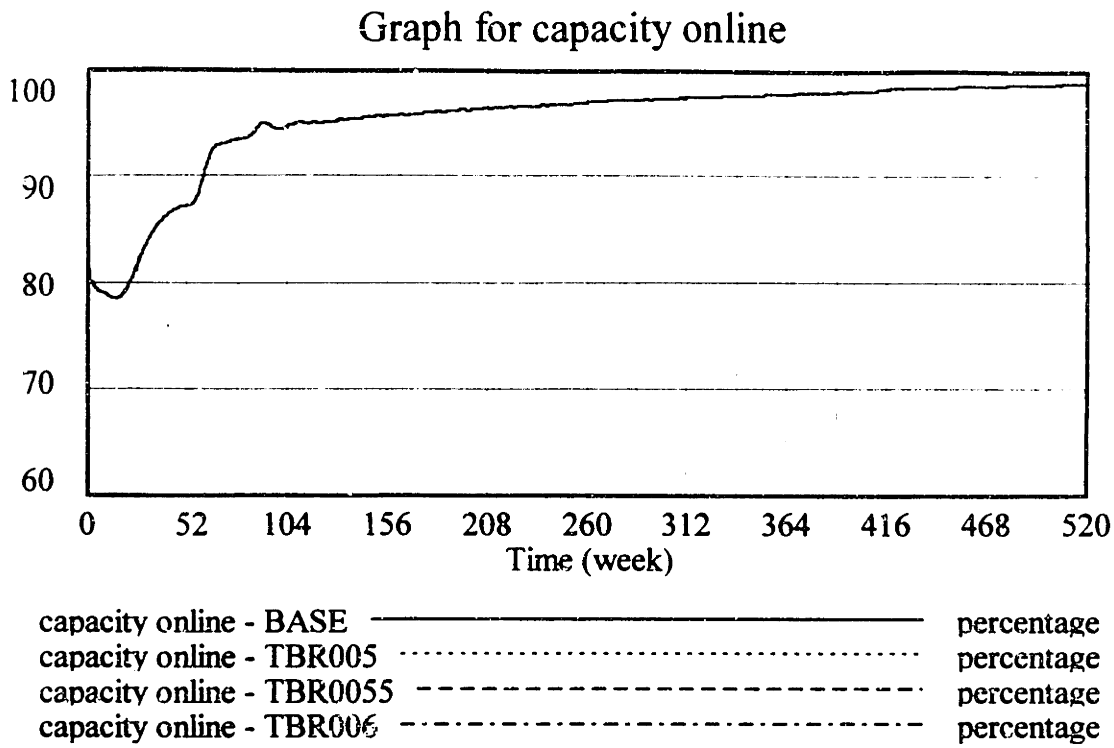
Variable 214



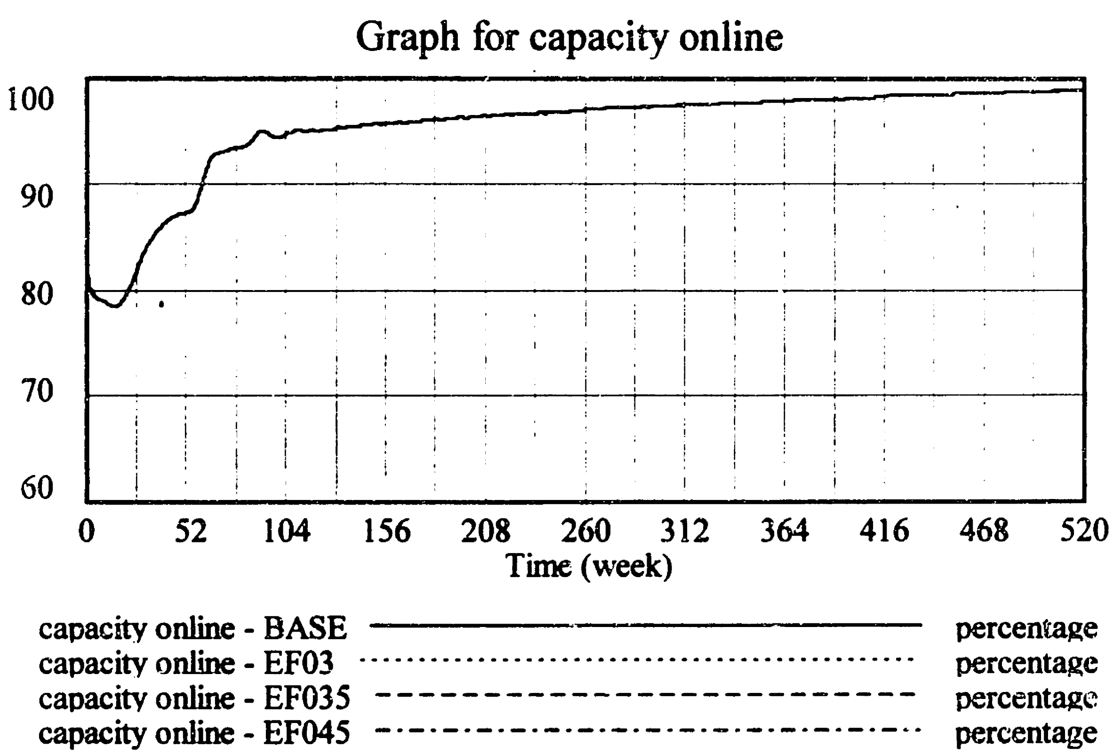
Variable 215



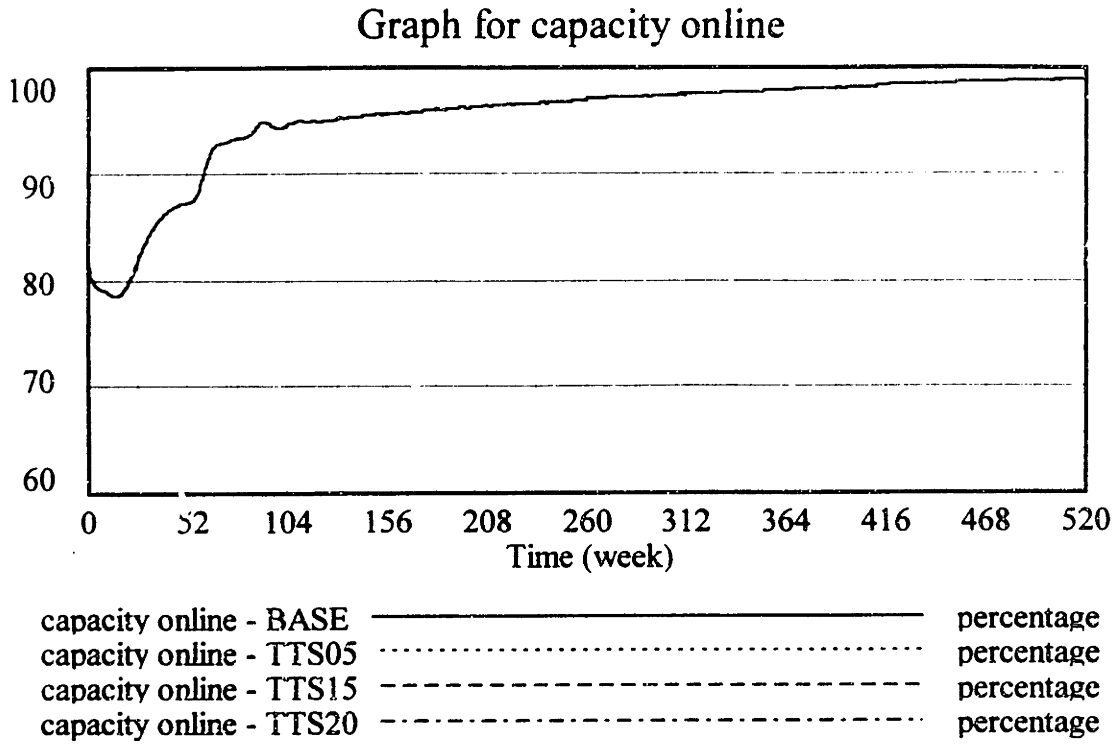
Variable 216



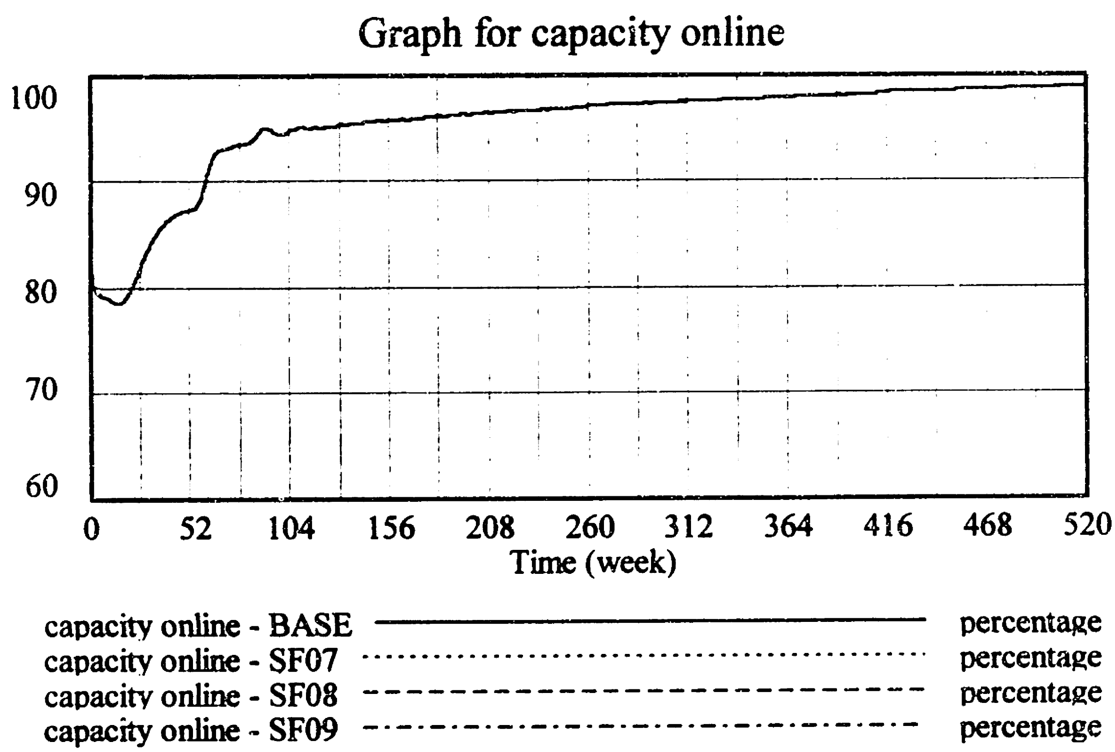
Variable 217



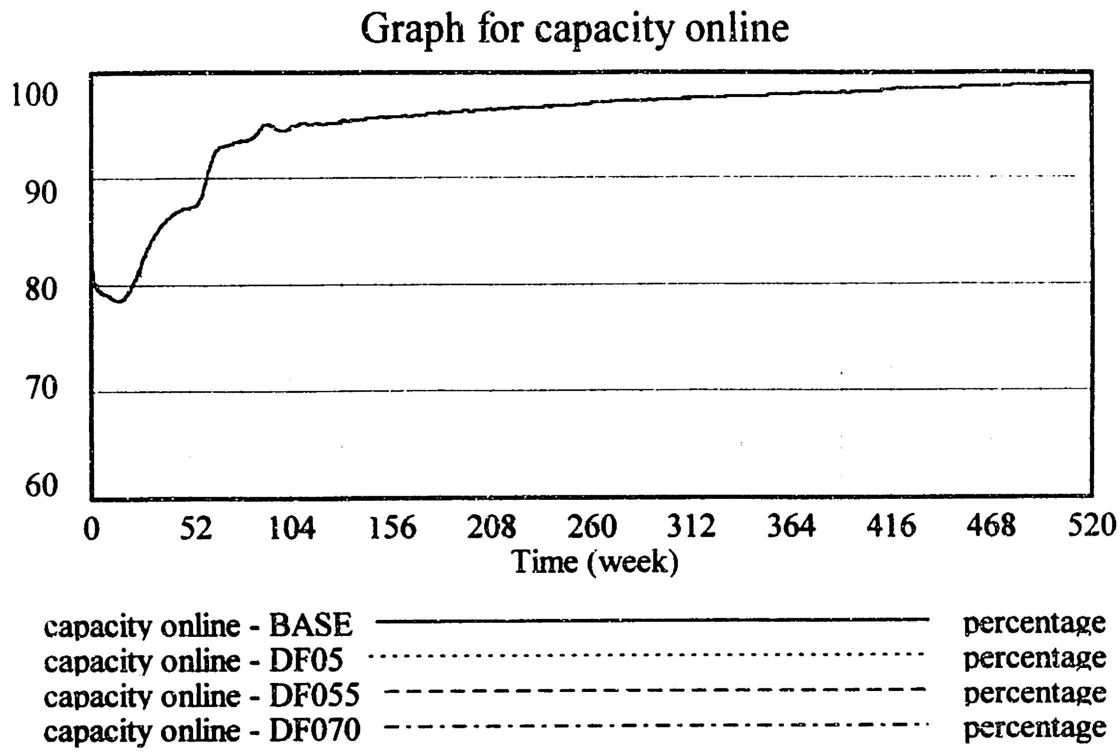
Variable 218



Variable 219



Variable 220



Variable 221